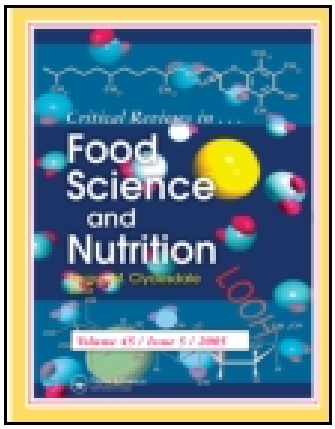

Critical Reviews in Food Science and Nutrition
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/bfsn20

Multiple Functional Ingredient Approach in Formulating Dietary Supplement for Management of Diabetes: A Review

Kanika Pawar [a] & Dilip Kumar Thompkinson [a]
[a] Dairy Technology Division , National Dairy Research Institute , Karnal , 132001 , India
Accepted author version posted online: 08 Mar 2013.Published online: 05 Feb 2014.

To cite this article: Kanika Pawar & Dilip Kumar Thompkinson (2014) Multiple Functional Ingredient Approach in Formulating Dietary Supplement for Management of Diabetes: A Review, Critical Reviews in Food Science and Nutrition, 54:7, 957-973, DOI: 10.1080/10408398.2011.621039

To link to this article: http://dx.doi.org/10.1080/10408398.2011.621039

Critical Reviews in Food Science and Nutrition, 54:957–973 (2014)

ISSN: 1040-8398 / 1549-7852 online
DOI: 10.1080/10408398.2011.621039

Taylor & Francis
Taylor & Francis Group

Multiple Functional Ingredient Approach in Formulating Dietary Supplement for Management of Diabetes: A Review

KANIKA PAWAR and DILIP KUMAR THOMPKINSON
Dairy Technology Division, National Dairy Research Institute, Karnal 132001, India

Food and nutrition science has moved from identifying and correcting nutritional deficiencies to designing foods that promote optimal health and reduce the risk of disease. Diabetes is rapidly emerging as a pandemic. It is also accompanied by several health implications viz. cardiovascular diseases, obesity, hypertension, cancer, depression, and eating disorders. International Diabetes Federation estimates that in 2010, India is home to 50.8 million diabetics and the number is expected to go up to a whopping 87 million by 2030. The primary goal of medical nutrition therapy was to design special dietary products for patients with hyperglycemia, intended in controlling postprandial plasma glucose fluctuations and hypercholesterolemic tendencies. However, an effective way to minimize these health risks could be through modifications in the diet by inclusion of multiple functional ingredients, aimed for their concerted role in management of individuals suffering with diabetes.

Keywords Diabetes, dietary supplement, dietary fiber, monounsaturated fatty acids, nutraceuticals, physiological effects, resistant starch

INTRODUCTION

With the evolution of novel technologies and scientific developments in the past decade, area of health foods has taken a new dimension. In addition, people throughout the world are becoming increasingly convinced that the foods they consume can not only modulate performance, but also influence their risk of acquiring a variety of diseases (Wrick, 1995). With the increased consumption of energy-dense food having high levels of sugar and saturated fat (SF) combined with sedentary lifestyle, diabetes has emerged as a growing epidemic across the world accompanied by other health implications viz. cardiovascular diseases, obesity, hypertension, cancer, depression, and eating disorders. The etiology of above mentioned diseases is complex, related to lifestyle, heredity, acquired physical and physiological disability, environment, and personality. The following text reviews various dietary approaches beneficial for the diabetic patients and growing market for health food supplements.

Address correspondence to Kanika Pawar, Dairy Technology Division, National Dairy Research Institute, Karnal 132001, India. E-mail: kanikapawar@gmail.com

DIETARY SUPPLEMENT/NUTRACEUTICALS

Dietary supplement (DS), also known as "food supplement or nutritional supplement," is a preparation intended to supplement the diet and provide nutrients, such as vitamins, minerals, fiber, fatty acids, amino acids, that may be missing or may not be consumed in sufficient quantity in a person's diet. Some countries define DSs as foods, while in others they are defined as drugs or natural health products. They are also defined as the substances, which are used to add nutrients to the diet or to lower risk of health problems, like osteoporosis or arthritis. DSs come in the form of pills, capsules, powders, gel tabs, extracts, or liquids. DS may be grouped into three major categories related to dietary function or origin: (1) substances with established nutritional function, such as vitamins, minerals, amino acids, and fatty acids; (2) botanical products and their concentrates and extracts; and (3) other substances with a wide variety of origins and physiological roles. The third category includes substances such as pyruvate, steroid hormone precursors, and chondroitin sulfate (Hathcock, 2001). The reasons individuals take DS probably vary as much as people do, but important motivations include ensuring nutritional adequacy, protecting tissue structures and functions, decreasing the risk of certain diseases and age-related changes, and enhancing physical performance.

Table 1 Selected nutritive nutraceutical

Nutraceutical	Benefits	References
Dietary fiber	May reduce appetite, lowers variance in blood sugar levels, reduces risk of heart disease, may reduce onset risk or symptoms of metabolic syndrome and diabetes, facilitates regularity, alleviates constipation, may reduce risk of colorectal cancer	Jenkins et al., 2001; Theuwissen et al., 2008
Monounsaturated acid and polyunsaturated fatty acids (PUFA, fish oil)	Lower risk of cardiovascular disease, lower risk of some cancers, enhanced immune system, improves insulin senstivity	Tanasescu et al. (2004); Susan et al. (2009)
Proteins peptides, amino acids, keto acids	Hypotensive, immune modulation, protective against oxidative stress, anticancer, antiviral effects anti-inflammatory, reduce cholesterol, anti-thrombic, control of weight gain, regulation of insulin turnover	Harper (2001), Walzem et al. (2002)
Minerals (magnesium, chromium, calcium, vanadium)	Blood glucose control, enhance the body's utilization of insulin, control insulin sensitivity	Mandal (2007)
Antioxidants vitamins (Vitamin C, Vitamin E, or ß-carotene)	Prevent cardiovascular disorders, protect cell membranes against free radical oxidative damages	AHA (2007); Azen et al. (1996)
Prebiotics	Improved gastrointestinal function, improves colonic health, SCFA production	Scholz-Ahrens et al. (2007); Roberfroid (2000)

The scientific evidence to support these functions varies greatly from one supplement ingredient to another.

Many DS are simply taken as part of a healthy lifestyle, but some are used to reduce risk of or modulate risk factors for specific chronic diseases, such as heart disease (vitamin E, folic acid, and garlic), cancer (selenium, vitamin E, and garlic) and certain birth defects (folic acid). Other DSs are used for short-term benefits such as sleep management (valerian and melatonin) and enhanced physical performance (pyruvate and creatine). DSs are regulated under food law.

A nutraceutical preparation may be considered a food or part of a food and provides medical or health benefits including the prevention and treatment of disease (DeFelice, 1992). Nutraceuticals have been defined as DSs that contain a concentrated form of a presumed bioactive substance used to enhance health in dosages exceeding those obtainable from normal foods, like vitamin supplements, ipriflavone tablets for osteoporosis or fish-oil capsules for lipid disorders (Jeffrey, 2005). Nutraceuticals may range from isolated nutrients, DSs and diets to genetically engineered "designer" foods, herbal products and processed products such as cereals, soups, and beverages (Andlauer and Fürst, 2002). Selected nutritive nutraceutical are listed in Table 1. And in India, these functional foods can include herbal extracts, spices, fruits, and nutritionally improved foods or food products with added functional ingredients (Kaushik and Kaushik, 2009).

Diabetes Scenario India and World

In recent years, India has witnessed a rapidly exploding epidemic of diabetes. Today, India leads the world with its largest number of diabetic people in given country. There are two main forms of diabetes—Type I (insulin-dependent) and Type II (Non-insulin-dependent). International Diabetes Federation which tracks the global spread of this scourge says that by the year 2010, the country will be home to 50.8 million diabetics, making it the world's unchallenged diabetes capital. And the number is expected to go up to an 87 million (8.4% of the country's adult population) by 2030. China stands second in this infamous table with 43.2 million diabetes cases at present, which is expected to increase to 62.6 million by 2030. The disease will prove costly for India, both in terms of lives lost and money spent. In India, around 10.07 lakh people in the age group of 20–79 years die every year—the majority being women (5.81 lakh by 2010). Diabetes will cost world economy to $376 billion in 2010, or 11.6% of total world healthcare expenditure. Though India will spend only 1% of the total diabetes spending worldwide, the amount itself is staggering—$2.8 billion. United States, on the other hand, will account for $198 billion or 52.7% of the total diabetes spending worldwide. By 2030, diabetes is expected to cost the world economy $490 billion. Globally, the number of diabetes patients has risen sharply. While in 1985, 30 million people had diabetes, the number rose to 150 million in 2000. By the year 2010, 285 million people (6.6% of the global population in the age group 20–79) were found to be diabetic. However, by 2030, an estimated 435 million people 7.8% of the adult population is expected to suffer from this disease. Age-wise, the International Diabetes Federation report says, the worst affected are the 40–59-year-olds. 132 million people in this age group are expected to suffer from diabetes by 2010. However, by 2030, this number will increase to 188 million. The report points out another interesting trend – women are the worst affected by this disease. In 2010, one million more women than men have diabetes (143 million women as against 142 million men). The difference is expected to increase to six million by 2030 (222 million women against 216 million men). The urban population, as expected, has a higher incidence of the disease. By 2010, the number of people with diabetes in urban areas will be 113 million compared to 78 million in rural areas. By 2030, it is expected that this discrepancy will increase to 228 million people with diabetes in urban areas and 99 million in rural communities. Majority of these deaths will be in India, China, US, and Russia (Sinha, Times of India and Oct 21, 2009).

DIABETES

Diabetes is a metabolic cum vascular syndrome of multiple etiologies characterize by chronic hyperglycemia with disturbances of carbohydrate (CHO), fat, and protein metabolism resulting from defects in insulin secretion, insulin action, or both. This disorder is frequently associated with long-term damage, which can lead to failure of organs like eyes, kidneys, nerves, heart, and blood vessels.

Epidemiology

Type 1 diabetes (insulin-dependent) is primarily due to autoimmune—mediated destruction of pancreatic beta cells, resulting in absolute insulin deficiency. While type 1 diabetes is also on the increase the actual numbers of people with type 1 diabetes in India is relatively speaking still small (ICMR, 2005). Type 2 diabetes (non-insulin-dependent) on the other hand accounts for over 90–95% of all diabetic people and is characterized by insulin resistance and/or abnormal insulin secretion, either of which may predominate (ICMR, 2005). The diabetes epidemic relates particularly to type 2 diabetes and is taking place both in developed and developing nations with particular reference to India and is predominantly due to changing demography and sedentary life style.

Therefore, the complete treatment of people with diabetes requires advocating a healthy life style with focus on increased physical activity and proper balanced diet to attain and maintain desirable body weight. Also, meticulous attention is to be given to achieve normoglycemia, control of hypertension and management of dyslipidemia. There is an urgent need for strategies to prevent the emerging epidemic of diabetes apart from treating diabetes and associated complications. Several factors are thought to contribute toward the acceleration of the epidemic, the most important being the rapid epidemiological transition due to urbanization and lifestyle changes seen in developing countries. Identifying the individuals at risk is essential in planning preventive measures.

POSSIBLE DIETARY MANAGEMENT TOWARDS DIABETIC CONTROL

The aims of dietary management are to achieve and maintain ideal body weight, euglycemia and desirable lipid profile, prevent and postpone complications related to diabetes and to provide optimal nutrition during pregnancy, lactation, growth, old age, and associated conditions, e.g., hypertension and catabolic illnesses.

The dietary recommendations should be individualized according to person's ethnicity, cultural and family background, and personal preferences and associated comorbid conditions. It should be flexible in variety and preparation of food choices and timing of meals according to person's daily routine.

Table 2 Dietary proportions of different constituents

Constituents	
Carbohydrates (complex)	50–65%
Fats	<25%
Saturated fatty acids	<8%
Polyunsaturated fatty acid	10%
Monounsaturated fatty acid	7%
Dietary cholesterol	<300 mg
Proteins	10–15%
Dietary fiber	40–50 g/24 h or 25 g/1000 kcal

Source: Katyal (1992); ICMR (2005).

Dietary Recommendations

Calorie needs for most diabetic patients are in the range of 1500–2100 kcal/day. However, their total caloric intake should not be allowed by more than 500 kcal/day depending upon their daily intake of various other foods. The CHO should provide 55–60%, proteins 10–15% while fats 20–25% of total calorie requirement in a typical diet. Dietary cholesterol should be minimal and in any case should not exceed 300 mg per day (ICMR, 2005). Table 2 lists the proportion of the dietary constituents.

Significance of Dietary/Nutritional Formulations

The major metabolic abnormality associated with the diabetes is hyperglycemia (Nathan et al., 2006). In the short term, (postprandial) hyperglycaemia can lead to polyuria, increased thirst, dehydration, weight loss, blurred vision, and fatigue. In the long term, elevated (postprandial) blood glucose levels play an important role in the occurrence of microvascular and macrovascular complications (Stettler et al., 2006). For these reasons, control of blood glucose, to achieve near-normal levels is a primary goal of diabetes therapy. Diabetes patients frequently present nutrient intake imbalances due to food restrictions. These patients may benefit from nutritional support. Food and nutrition interventions that reduce postprandial blood glucose excursions are important in this regard, since dietary CHO is the major determinant of postprandial glucose levels in diabetic patients (Bantle et al., 2006). Hence, nutritional/DSs specially developed for patients with hyperglycaemia are aimed at controlling (postprandial) plasma glucose concentrations. Hence, a systematic review showcasing the use of constituent sources specifically for the diabetes formulae is associated with improved glycaemic control.

CONSTITUENTS

Fat

According to the dietary recommendation for diabetic patients, the fats should provide 20–25% of total calorie requirement. The SFs should be <7% of total calorie intake while

rest should be in form of monounsaturated fatty acid (MUFA) and polyunsaturated fatty acid (PUFA). The ratio of MUFA and PUFA should be nearly equal to one. Dietary cholesterol should be minimum and in any case should not exceed 300 mg per day (ICMR, 2005).

Physiological Effects

Diabetes is determined primarily by lifestyle and genes, dietary composition may also affect both its development and complications. Dietary fat is of particular interest because fatty acids influence glucose metabolism by altering cell membrane function, enzyme activity, insulin signaling, and gene expression (Riserus et al., 2009). The association between dietary fat and CHD has been extensively studied. Diets high in saturated fatty acids (SFAs) and trans-fatty acids increase LDL cholesterol levels, and in turn, the risk of heart disease. Taken together, the evidence suggests that replacing SFs and trans-fatty acids with unsaturated (polyunsaturated and/or monounsaturated) fats has beneficial effects on insulin sensitivity and is likely to reduce risk of type 2 diabetes (Riserus et al., 2009). Among polyunsaturated fats, linoleic acid from the n-6 series improves insulin sensitivity. The given physiological effects focus on the association between the types of dietary fat and diabetes risk.

Insulinotropic Effects

Rasmussen et al. 1993 noted a reduction in peak plasma glucose concentration with the consumption of a MUFA-rich diet. Joannic et al. (1997) used the two kinds of fat as a mixture of high-oleic sunflower (70%) and rapeseed (30%) oils with a high ratio of MUFA to PUFA (4.3) and a mixture of sunflower (60%) and soybean (40%) oils with a MUFA-PUFA ratio (0.4). Results showed that the degree of unsaturation of fat influenced the glucose and insulin responses to mixed meals. Thirty minutes after both meals, glucose and insulin responses were lower with PUFA than with MUFA meals. Thomsen et al. (1999) examined the acute effect of different fats on postprandial lipemia and glucagon like peptide-1 (GLP-1) concentrations in healthy volunteers and showed that olive oil (OLO) induced higher concentrations of GLP-1 and gastric inhibitory peptide than did butter. If a nutrient were to be identified that augments the chronic release of GLP-1, it would be a potential treatment for type 2 diabetes because it would improve glycemic control and insulin sensitivity.

Brynes et al. (2000) investigated whether chronic intake of MUFAs or PUFAs improves insulin sensitivity in people with type 2 diabetes via stimulation of the endogenous gut hormone GLP-1 amide. Nine overweight people with type 2 diabetes received isoenergetic high-MUFA (20.3 $\pm$3.5% of total energy) or high-PUFA (13.4 $\pm$1.3%) diets for 24 days. Despite a significant change in the plasma triacylglycerol linoleic-oleic acid ratio (L:O) with both diets (MUFA: from 0.46 ± 0.03 to 0.29 ± 0.02; PUFA: from 0.36 ± 0.04 to 0.56 ± 0.05) and the phospholipid L:O (1.7 ± 0.1 to 2.0 ± 0.3) during consumption of the PUFA diet, this change was not associated with a change in insulin sensitivity, measured by the short-insulin-tolerance test. There was a significant reduction in the ratio of total to HDL cholesterol during consumption of the PUFA diet (5.2 ± 0.4 compared with 4.7 ± 0.3) but no change with the MUFA diet. There was no change in the fasting or postprandial incremental area under the curve (AUC) in response to an identical standard test meal for glucose, insulin, triacylglycerol, nonesterified fatty acids, or GLP-1. Other diet studies that suggested a positive effect on insulin sensitivity have been conducted over a similar length of time (Parillo et al., 1992). Salmeron et al. (2001) found no association between total fat intake and risk of type 2 diabetes. However, PUFA intake was associated with a substantial reduction in risk, and trans-fatty acids and dietary cholesterol were associated with increased risk. They estimated that replacing 5% of energy from SFA with energy from PUFA was associated with a 35% lower risk and that replacing 2% of energy from trans-fatty acids with PUFA was associated with a 40% lower risk. In diabetic patients who consumed diets enriched with trans-fatty acids (20% of energy) or SFAs (20% of energy) for 6 week, the postprandial insulin response increased by 59% and 77%, respectively, compared with the effects of an isoenergetic diet with 20% of energy from nonhydrogenated MUFAs (Christinsen et al., 1997). In metabolic studies, exchanging SF for CHOs increases both LDL and HDL cholesterol, whereas exchanging monounsaturated and polyunsaturated fat for SF lowers LDL cholesterol. Monounsaturated fat apparently does not result in lower HDL cholesterol when it is used to replace SF, whereas the effect of polyunsaturated fat is less clear (Lada and Rudel, 2003).

Yokoyama et al. (2008) used high fat and reduced CHO formula, which was developed to avoid a rapid rise in plasma glucose concentration by replacing CHO content with fat. This formula provides 49.3% of energy as fat, 34.3% as CHO and 16.4% as protein while the oleic acid (a typical MUFA) accounts for 69.7% of the fatty acids contained from OLO. Postprandial plasma glucose and insulin response were significantly lower in all subjects. No differences were observed in free fatty acids, triglycerides, and plasma glucagon between the two diet groups. Susan et al. (2009) reported that changes in dietary fat composition could lower the risk of developing metabolic syndrome. He investigated the effect of a SFA – and a MUFA – rich diet on insulin sensitivity, serum lipids, and gene expression profiles of adipose tissue in subjects at risk of metabolic syndrome. They have found that consumption of the SFA diet resulted in increased expression of genes involved in inflammation processes in adipose tissue, without changes in morphology or insulin sensitivity. The MUFA diet led to a more anti-inflammatory gene expression profile, which was accompanied by a decrease in serum LDL-cholesterol concentrations and an increase in plasma and adipose tissue oleic acid content (Susan et al., 2009).

Tanasescu et al. (2004) estimated that replacing 5% of energy from SF with equivalent energy from CHOs was associated

with a 22% lower risk of CVD. The same replacement with monounsaturated fat was associated with a 37% lower risk of CVD. Among diabetic persons, replacement of SF with monounsaturated fat may be more effective in lowering CVD risk than is replacement with CHOs. Anette et al. (2008) divided the diet into MUFA diet having high amount of MUFAs (>20% of energy), low fat diet contributing 20–30% of energy and control diet contributing 35% of energy (>15% of energy as SFA). Compared to both low fat and control diet, the MUFA diet results in reduction in both fasting glucose and insulin levels. Ramesh et al. (2005) reported that dietary substitution of sesame oil showed a better reduction of blood glucose 322.61 + 9.49 to 222.02 + 8.27) than groundnut oil (GNO) in STZ-diabetic rats. However, Ramesh et al. (2006) observed that the normal and diabetic rats fed on 8% GNO diet, results in a significant reduction in glucose (244.04 ± 11.66) levels from elevated levels of glucose (322.61 ± 9.49) along with insulin levels.

Hypocholesterolemic Effects

Milk Fat (Desi Ghee) not only contains small amount of cholesterol (2–3 mg/gram); the absorption of dietary cholesterol in humans is only 10–14%. Hence, from a diet containing 50 grams ghee, the cholesterol absorption will be only 20–30 mg, which is negligible in view of 1–4 g cholesterol synthesized daily in liver to meet its requirement for replacement of tissue and synthesis of hormones and other molecules in the body. Further milk fat is also rich in short and medium chain fatty acids which do not raise serum cholesterol. Recent research (Warensjo et al., 2010) on biomarkers of milk fat and the risk of myocardial infarction in men and women have found that the people containing more dietary fat were at lower risk of heart attack; for women the risk was reduced by 26%, while for men it was lowered by 9%. An experiment with the volunteers has also shown that cholesterol level does not rise even when the daily consumption of milk exceeds 2 L. On the contrary, the cholesterol levels were often found to decrease with increased intake of milk. Bhatia and Kansal (2011) fed high energy diet to rats (both cow and buffalo ghee and soyabean oil). They reported that rise in plasma cholesterol and triglycerides were significantly higher on soyabean oil than on cow and buffalo ghee diets. They postulated that consuming desi ghee increases plasma HDL levels which carries cholesterol from tissue to liver for its breakdown and subsequent elimination through bile. Rats fed on ghee diets registered significantly lower contents of cholesterol and triglycerides in aortic tissue compared to soyabean oil fed rats. Milk contains certain less characterized factors that reduce cholesterol biosynthesis and enhance cholesterol breakdown in liver, which are responsible for serum cholesterol lowering effects reported in human as well as in experimental animals (Aggarwal and Kansal, 1991).

Diets high in MUFAs have been found to be relatively hypocholesterolemic or hypotriacylglycerolemic. Nagaraju and Belur (2008) studied the effect of native (ground nut oil) through blends consisting of coconut oil (CO) with GNO or CO with OLO. In this study, rats were fed with native, blend, and interesterified oils at 10% level for 60 days. Among the different oils, GNO has lowered the serum cholesterol by 24%, LDL + VLDL-cholesterol level by 40%; TG levels were decreased by 14% while phospholipid level was decreased by 22%. Ramesh et al. (2006) noticed a significant reduction in TC, VLDL-C, LDL-C, and TG while an elevation in HDL-C was observed when the diabetic rats were fed on 8% GNO diet.

Studies with both humans and experimental animals have demonstrated that dietary SF increases plasma total and LDL-cholesterol concentration, whereas PUFA lower both these parameters. In addition, dietary MUFA, like oleic acid, has also been shown to be hypocholesterolemic and is as effective as linoleic acid in decreasing LDL cholesterol (Kris- Etherton et al., 1997). Because an increased LDL concentration enhances risk for coronary heart disease, recommendations have been made to reduce intake of dietary SFAs and increase the consumption of PUFA and MUFA (AHA, 1990). According to the Indian Council of Medical Research, the desirable proportions of saturated acid, oleic acid, and PUFA in the dietary fats should be in the proportion of about 1:1:1. According to the American Heart Association, the optimum intake of fat for an adult is 30% of total calorie and the ratio of SFA/MUFA/PUFA to be 1:1:1 (AHA, 1990)., which was also in tune with the recommendations given by health agencies in India.

In the past, MUFAs, on the other hand, were considered to be neutral with regard to their influence on serum lipids and lipoproteins (Keys et al., 1965). Recent findings, however, suggest that MUFAs may also have favorable effects on blood lipid concentrations as well as on the risk of cardiovascular heart disease (CHD). Epidemiological studies have revealed that compared with other industrialized countries there is lower CHD mortality in the Mediterranean countries where the diet is traditionally rich in OLO, which is characterized by its high content of the monounsaturated oleic acid (C18: 1n-9) (Keys et al., 1986). Furthermore, clinical trials have shown a decrease in total and LDL cholesterol concentrations ensuing to a substitution of dietary SFA by MUFA. Furthermore, MUFA intake has been found to induce a lower satiety level and a larger subsequent energy intake than do PUFA and SFA intakes (Lawton et al., 2000) and to increase body weight more than PUFA intake.

Mensink and Katan (1989) observed only slight changes in HDL cholesterol concentrations on their high-fat diets with moderate amounts of either PUFA (12% of energy) or MUFA (15% of energy). Wardlaw et al. (1991) examined in two experiments the effects of PUFA- or MUFA-rich diets, each having ∼40% of energy as fat, compared with SFA-rich diets. Wahrburg et al. (1992) found that a low-fat, MUFA-rich diet is as effective as a low-fat, PUFA-rich diet in lowering total and LDL cholesterol, but both also lowered HDL cholesterol concentrations. The MUFA-rich diet may be more advantageous than the PUFA rich one because it does not lower apolipoprotein A-I concentrations as much as the PUFA-rich diet. Berry et al. (1991) compared two moderate-fat diets with 8% of energy as SFA

and with an MUFA or PUFA content of ∼17% of energy each. Although the habitual diet of the subjects had only a slightly higher SFA content (10.5% of energy), the observed significant reductions in total and LDL cholesterol values with both test diets. Similar results could be obtained for patients with noninsulin-dependent diabetes mellitus who further showed an improved glycemic control after partial replacement of complex CHOs with MUFAs (Garg et al., 1988).

Mayer-Davis et al. (1997) reported positive associations with saturated and MUFAs and an inverse association with PUFA intake. Due et al., 2008 compared the effects of three diets on the risk factors for diabetes and cardiovascular disease during a 6-months controlled dietary intervention. Nondiabetic overweight men and women were randomly assigned to a diet providing a moderate amount of fat (35–45% of energy) and >20% of fat as MUFAs (MUFA diet; Vegetable oil (Olive and rapeseed oil), to a low-fat (20–30% of energy) diet (LF diet), or to a control diet (35% of energy as fat). Protein constituted 10–20% of energy in all three diets. In the MUFA group, fasting insulin decreased by 2.6 ± 3.5 pmol/L, the homeostasis model assessment of insulin resistance by 0.17 ± 0.13, and the ratio of LDL to HDL by 0.33 ± 0.13; in the LF group, these variables increased by 4.3 ± 3.0 pmol/L and 0.17 ± 0.10 and decreased by 0.02 ± 0.09, respectively; and in the control group, increased by 14.0 ± 4.3 pmol/L, 0.57 ± 0.17, and 0.05 ± 0.14, respectively. This is in line with other findings showing that a diet higher in unsaturated fat may improve insulin resistance (Pelkman et al., 2004) compared with a diet high in CHO, even though the total fat content increased.

PROTEIN

Generally, protein has only been considered in the context for maintenance of lean body mass, i.e., that needed to maintain nitrogen balance, whether people have diabetes or not. A for dietary protein in the management of hyperglycemia either has not been considered or has been considered only concerning the amount of glucose that theoretically can be derived from the constituent amino acids through gluconeogenesis (Eilat Adar et al., 2008).

According to the dietary recommendation for diabetic patients the protein should provide 10–15% of total calorie requirement (ICMR, 2005) while it should provide 10–20% of energy according to ADA dietary recommendations (ADA, 2006). In persons with type 2 diabetes, protein ingestion actually results in a small decrease in postprandial glucose concentrations. Protein can be incorporated in various forms like soya protein isolate, casein or caseinates, whey proteins, skim milk powder, etc.

The awareness of the insulinotropic effects of milk has been growing (Ostman et al., 2001). It seems that milk proteins, in particular, the whey fraction, have a stimulating effect on insulin secretion in healthy subjects (Nilsson et al., 2004). The key mechanisms is not known, but elevated concentrations of specific insulinogenic amino acids as well as bioactive peptides, either originally present in whey or formed during digestion, are possible. Particularly, glucose-dependent insulinotropic polypeptide (GIP) has been reported to increase significantly in blood plasma after whey ingestion (Nilsson et al., 2004). In addition to GIP, GLP-1 is known to have insulinotropic properties during normal plasma glucose concentrations (Vilsboll et al., 2003). Previously, skim milk was reported to have insulinotropic effects in untreated type 2 diabetic subjects (Gannon et al., 1986). It is known that proteins vary with respect to their effect on glucose metabolism in type 2 diabetic subjects and may stimulate insulin release and attenuate blood glucose response. Coingestion of dietary protein and glucose may have synergistic effects on insulin response (Gannon et al., 1992). Milk, skim milk, and milk products can exert a hypocholesterolemic effect in humans and experimental animals (Richardson, 1978). Milk constituents such as orotic acid, lipoproteins, lactose, calcium, or hydroxymethyl glutaric acid have been suggested as hypocholesterolemic factors (Thompson et al., 1982). However, there is still no direct evidence for the existence of a hypocholesterolemic milk factor, but it appears that from all milk products tested skim milk has the greatest hypocholesterolemic tendency (Golay et al., 1990).

Whey Protein Concentrate

Whey proteins are excellent source of dietary nitrogen and essential amino acids. They also act as techno-functional ingredients in many formulated food systems due to their good solubility, surface activity, and gelling properties. In addition, whey proteins and their associated peptides display significant potential as functional food ingredient. The growing interest in the functional use of whey proteins has stimulated the production of wide range of whey protein products like whey protein concentrate and whey protein isolate. With increasing protein content, the whey protein concentrates provide greater nutritional value as well as improved functional properties such as emulsification, foaming, water binding, viscosity building, and gelling to foods. Whey protein is commonly marketed and ingested as a DS, and various health claims have been attributed to it in the alternative medicine community (Marshall, 2004). Whey protein isolates are widely used as nutritional supplements in sports drinks and health foods and protein supplements (Augustine et al., 2003).

Physiological Effects

The effects of whey protein on human health are of great interest and this protein mixture is being investigated as a way of reducing disease risk, or as a supplementary treatment for several diseases. Some preclinical studies in rodents have suggested that whey protein may influence glutathione (GSH) production (due to high content of amino acid cysteine, which is a substrate for biosynthesis of GSH (Xiao et al.,

2006) and possess anti-inflammatory (resulted from the immunomodulatory and immunosuppressive effects imparted by number of whey proteins (WPC, α-LA, β-LG, and LF) on the body's immune system) (Gill et al., 2000) or anti-cancer properties (due to an elevation of GSH levels in several tissues) (Bounous and Molson (2003); however, human data are lacking (Xiao et al., 2006).

Insulinotropic Effects

Whey proteins contain more essential amino acids and branched chain amino acids than most other food proteins, and as a consequence are associated with the modulation of insulin responses in humans (Pfeuffer and Schrezenmeir, 2007). Individual amino acids such as phenylalanine, lysine, leucine, and arginine have potent insulin stimulation properties and are present in moderate quantities in the individual whey proteins. Additionally branched chain amino acids from whey including isoleucine, leucine, and valine have been linked with postprandial stimulation of insulin and increased plasma amino acid levels (Matthews, 2005). Calbet and MacLean (2002) reported a two- to fourfold increase in insulin secretion in six human test subjects following administration of a whey hydrolysate (0.25 g/kg body mass) after 30 min compared to the response obtained with a glucose solution(25 g/L) and cow's milk. The insulin response was correlated to the increase in plasma levels of leucine, isoleucine, valine, phenylalanine, and arginine. According to Frid et al. (2005), supplementation of meals having a high glycemic index (GI) with whey proteins increased insulin secretion and improved blood glucose control in type 2 diabetic subjects. When whey was included in the high glycemic breakfast and lunch meals in exchange for lean ham and lactose the insulin responses were higher after both breakfast (31%) and lunch (57%) than when whey was not included. After lunch, the blood glucose response was significantly reduced by 21% along 120 min AUC after whey ingestion. Postprandial GIP (GIP) responses were higher after whey ingestion. A threefold increase in insulin response was reported following the administration of glucose with whey (75 mg) in mice that was superior to the 1.5-fold increase with 34 mg oleic acid (Gunnarsson et al., 2006). The insulinotropic effect of whey protein is not necessarily observed in longer term intervention studies. Insulin-resistant rats were fed a high protein diet for 6 weeks containing either 80 or 320 g protein/kg WPC or meat protein (Belobrajdic et al., 2004). WPC reduced plasma insulin concentration by 40% and the insulin glucose ratio, a measure of insulin resistance, was lower in rats fed WPC than in rats fed red meat. Trecroci (2005) observed that supplementing high GI meals with whey proteins increases insulin secretion and improves blood glucose control in subjects with type 2 diabetes. It can be concluded that whey proteins and their associated peptides may serve as exogenous regulators of incretin hormones with beneficial influences in humans especially those affected by diabetes.

Hypotensive Effects

Hypertension or high blood pressure (BP) is a controllable risk factor in the development of a range of cardiovascular disease states. It is well recognized that risk of developing heart disease and stroke significantly increases at systolic/diastolic (DBP) values above 115/75 mm/Hg. Hypertension is estimated to effect less than 25% of the global population (Health, National Centre for Health Statistics, 2002). It is reported that a 5 mm reduction in DBP can reduce the risk of cardiovascular disease by less than 16%.

Numerous peptide sequences derived from food protein sources have been reported to inhibit angiotensine-converting enzyme (ACE), an activity which plays a central role in BP control. The area of milk protein-derived ACE inhibitory peptides has been extensively reviewed (Fitz-Gerald and Meisel, 2003; Korhonen and Pihlanto-Leppala, 2006). Whey proteins contain peptide sequences within their primary structures, which have the ability to inhibit ACE. A number of studies have been performed on the hypotensive effects of whey-derived peptides in spontaneously hypertensive rat (SHR). Significant decreases in BP have been observed following administration of these peptides. While α-lactoferin, α- Lactalbumin f(50–53), displays ACE inhibitory activity, its BP-lowering effect following intravenous administration to SHR was via interaction with opioid receptors.

Sodium Caseinate

Milk proteins are of high nutritional quality and therefore they are used extensively in dietary preparations. It is also used as a DS by bodybuilders and other athletes, who ingest it, with breakfast, or as postwork out meal, as it breaks down at a slower rate than whey protein, thus supplying the body with a sustained protein release. Casein was shown to be insulinotropic by Rabinowitz et al. in 1966 and has been studied on a cellular level and on a whole body level in vivo in humans. Sener and Malaisse (1980) observed that the addition of leucine to the incubation medium stimulates insulin release by pancreatic β cells in vitro. Leucine activates glutamate dehydrogenase activity. This subsequently leads to an increase in tricarboxylic acid cycle activity and is attended by increased insulin production. By using infusions, it was shown in humans that, several amino acids lead to significant increases in plasma insulin. Westphal et al. (2004) found that casein moderately reduces and delays the postprandial lipemia and markedly lowers postprandial and postabsorptive concentrations of FFAs. Also postulated at, insulinotropic action of casein is responsible for both of these effects. In case of nondiabetic subjects, incorporation of 50 g sodium caseinate in mixed meal showed an increase in the insulin area under curve by 29% up to 3 h. The casein-induced rise in insulin also occurred when oligosaccharides were given in addition, leading to a lowering of the peak glucose

concentration by 10% after 60 min confirming early insulinotropic action of casein.

CARBOHYDRATE

CHOs are well known as quick energy source which is a major fuel for all of the body's cells and the only source of energy for the brain and red blood cells. Except for fiber, which cannot be digested, both simple and complex CHOs are converted into glucose. The dietary macronutrient that raises postprandial serum glucose and insulin most potentially is CHO (Buse et al., 2003). This observation led to the use of diets low in CHO for the treatment of diabetes before insulin or other medication therapies were available. Insulin-deficient individuals are advised to estimate the amount of dietary CHO in their meal for deciding dosage of insulin. This strong relationship between dietary CHO and postprandial serum glucose led to the development of medications that block CHO absorption for the treatment of type 2 diabetes (Chiasson et al., 2002). The most effective dietary management for type 2 diabetes is calorie restriction for weight reduction, since most subjects with this type of diabetes are metabolically obese. To hinder the fluctuation in glucose level provided by the CHOs, the low calorie sweeteners or other alternative sources of CHOs are found to be best alternative for treatment of diabetes. According to the dietary recommendation for diabetic patients the CHO should provide 55–65% of total calorific requirement (ICMR, 2005) while the CHO intake should be 60–70% of energy according to ADA dietary recommendations (ADA, 2006).

Resistant Starch

Starch is the major source of CHO in the human diet. Chemically, starches are polysaccharides composed of α-D-glucopyranosyl units linked together with α-D-(1–4) and/or a-D-(1–6) linkages. Two crystalline structures of starch have been identified (an "A" and "B" type), which contain differing proportions of amylopectin. A-type starches are found in cereals, while B-type starches are found in tubers and amylose-rich starches. In general, digestible starches are broken down (hydrolyzed) by the enzymes α-amylases, glucoamylase, and sucrase–isomaltase in the small intestine to yield free glucose which is then absorbed (Nugent, 2005). However, not all starch in the diet is digested and absorbed in the small intestine (Ratnayake and Jackson, 2008). Nutritionally, starches are classified into rapidly digestible starch (RDS), slowly digestible starch (SDS), and resistant starch (RS) on the basis of their digestion rate in humans. A low ratio of RDS to the sum of SDS and RS in a starchy food indicates a low GI (Englyst et al., 1999). Foods with a low GI improve satiety (Warren et al., 2003) and may help prevent obesity and type II diabetes (Jenkins et al., 2001).

RS is a linear molecule of α-1,4-D-glucan, essentially derived from the retrograded amylose fraction, and has a relatively low molecular weight (1.2× 105 Da) (Tharanathan, 2002). It is an extremely broad and diverse range of materials and a number of different types exist. They are mostly defined according to physical and chemical characteristics (Nugent, 2005). RS is the fraction of starch which is not hydrolyzed to D-glucose in the small intestine within 120 min of being consumed, but which is fermented in the colon. It is prepared through chemical modifications, such as phosphorylation, which changes its functionality and digestibility. Different levels and chemical forms of phosphate esters may give different functionalities to phosphorylated starch. Monosubstitution of starch with phosphate groups has been shown to decrease starch digestibility with α-amylase. However, it is the phosphate cross-link that can dramatically decrease starch digestion by α-amylase. A distarch phosphate with a high level of phosphorus content ($\sim$0.4%) is high in RS and total dietary fibre content (Woo and Seib, 2002). Distarch monophosphate, monostarch monophosphate, monostarch diphosphate, and cyclic monostarch monophosphate have been found in the phosphorylated cross-linked RS.

Digestion of RS

The concept of RS is based on the inability of digestive enzymes to hydrolyze some physical and chemical forms of starch in foods in vivo or in vitro. Food that is passed into the small intestine is termed "chime" which is blended with bile, pancreatic α-amylase, and amylolytic and other enzymes such as enterokinase, sucrase, maltase, and lactase secreted by the epithelial cells of the small intestine (Perera et al., 2010).

These enzymes are responsible for the hydrolysis of CHOs into monosaccharides. Chyme that is not hydrolyzed into absorbable molecules in the small intestine, moves into the colon along with nonstarch polysaccharides (NSP) and undergoes bacterial fermentation. The resulting short-chain fatty acids (SCFAs) are absorbed in the colon and provide 5–10% of the energy requirement of humans. Approximately 80–90% of the RS that passes into the human colon is fermented and the remainder is released with the feces. Individual variations in the microbial population of the colon can influence significantly the degree of RS fermentation. The presence of RS in the diet decreases considerably the bacterial fermentation of NSP, which is useful as NSP increase the bulk of the excreta and improve its water holding capacity (Cummings et al., 1996).

Dietary Intake

Several studies have attempted to quantify the dietary intake of RS in different populations. Worldwide, the dietary intake of RS varies considerably. It is estimated that RS intake in developing countries with high starch consumption rates ranges from approximately 30–40 g/day (Baghurst et al., 2001). Intakes in the EU are thought to be from 3 to 6 g/day (Dyssler and Hoffmann, 1994), and 5–7 g/day in Australia (Baghurst et al.,

Table 3 Physiological effects of resistant starch

Protective effect	Potential physiological effects	
Diabetes	Control of glycemic and insulinemic responses	Behall et al. (2006); Higgins (2004)
Colorectal cancer, ulcerative colitis, inflammatory bowel disease, diverticulitis, and constipation	Improved bowel health	Nugent (2005); Sharma et al. (2008)
Cardiovascular disease, lipid metabolism syndrome, cholesterol, and triglycerides	Improved blood lipid profile	Nugent (2005); Sharma et al. (2008)
Colonic health	Prebiotic and culture protagonist	Scholz-Ahrens et al. (2007)
Obesity	Increased satiety and reduced energy intake	Higgins (2004); Nugent (2005)
Osteoporosis, enhanced calcium absorption	Increased micronutrient absorption	Scholz-Ahrens et al. (2007)

2001). Australia's Commonwealth Scientific and Industrial Research Organization has recommended that the total intake of RS should be around 20 g a day based on a study by Baghurst et al. (2001) for good health. However, RS could make a valuable contribution to dietary fibre intakes, as it is fermented slowly in the large bowel and is therefore tolerated better than other soluble fibres (Lunn and Buttriss, 2007).

Physiological Effects

RS has received much attention for both its potential health benefits and functional properties. RS is one of the most abundant dietary sources of non- digestible CHOs (Nugent, 2005) and could be as important as NSP in promoting large bowel health and preventing bowel inflammatory diseases and colorectal cancer. A number of physiological effects have been ascribed to RS, which have been proved to be beneficial for health (Sajilata et al., 2006) and are listed in Table 3.

RS positively influences the functioning of the digestive tract, microbial flora, the blood cholesterol level, the GI, and assists in the control of diabetes. There is also increasing interest in using RS to lower the energy value and available CHO content of foods. RS can also be used to enhance the fiber content of foods and is under investigation regarding its potential to accelerate the onset of satiation and to lower the glycemic response The potential of RS to enhance colonic health, and to act as a vehicle to increase the total dietary fiber content of foodstuffs, particularly those which are low in energy and/or in total CHO content (Nugent, 2005). RS acts largely through its large bowel bacterial fermentation products which are, in adults, SCFAs (Topping et al., 2003) but interest is increasing in its prebiotic potential.

Hypoglycemic Effects

Glycemic Index

The GI of starchy foods may depend upon various factors such as the amylase/amylopectin ratio, the native environment of the starch granule, gelatinization of starch, water content, and baking temperature of the processed foods. Thus, the factors affecting the GI values are in accordance with those of RS formation. With glucose as reference, reported GI values range from about 10 for starch from legumes to close to 100 in certain potato or rice products and breakfast cereals (Sharma et al., 2008).

Significance in Diabetes

The foods containing RS reduce the rate of digestion. The slow digestion of RS has implications for its use in controlled glucose release applications (Sajilata et al., 2006) and therefore, a lowered insulin response and greater access to the use of stored fat can be expected (Nugent, 2005). This is clearly important for diabetes and has led to major changes in dietary recommendations for diabetics (Cummings et al., 2004). The metabolism of RS occurs 5–7 h after consumption, in contrast to normally cooked starch, which is digested almost immediately. Digestion over a 5–7 h period reduces postprandial glycemia and insulinemia and has the potential for increasing the period of satiety (Reader et al., 1997).

There have been a number of studies on the effects of different forms and doses of RS on glucose and insulin responses but the data are contradictory (Sharma et al., 2008). In a study on humans, Reader et al. (1997) reported that the consumption of RS3 resulted in lower serum glucose and insulin levels than obtained with other CHOs. The study also showed that food containing RS decreased postprandial blood glucose and might play a role in providing improved metabolic control in type II diabetes. From a human study, using a commercial RS3 ingredient (CrystaLean®), the maximum blood glucose level was found to be significantly lower than that of other CHOs (simple sugars, oligosaccharides, and common starch). Higher GI values have been reported in humans consuming potatoes and cornflakes – foods that contain significant amounts of retrograded starch. In general, positive effects were usually observed shortly (within the first 2–8 h) after heavy meal (Higgins, 2004). They suggested that RS must contribute at least 14% of total starch intake in order to confer any benefits to glycemic or insulinemic responses. An RS3-containing bar decreased postprandial blood glucose and could play a role in providing improved metabolic control in type II diabetes (noninsulin dependent) (Sajilata et al., 2006). More recently, a study showed that RS reduces levels of glucose dependent insulinotropic polypeptide m-RNA along the jejunum and ileum in both normal and type 2 diabetes rats (Fuentes-Zaragoza et al., 2010).

Chemically-modified starches (RS4) have also been found to generate different glucose responses. The effect of two test meals

containing 1–2% acetylated potato starch and beta cyclodextrin enriched potato starch (2–3%), respectively, was studied in humans and only the latter was found to lower body glucose levels (Raben et al., 1997). This may be due to the more distal absorption of beta cyclodextrin in the intestine or to delay gastric emptying. As RS has a low glycemic response, adding it as an ingredient to foods will help lower the overall GL value of the food (particularly, if it is replacing existing readily absorbed forms of CHO). Tamimi et al. (2010) compared the postprandial glycemic and insulinemic responses to nutrition bars containing either cross-linked RS type 4 (RS4XL) or standard wheat starch in normoglycemic adults. The volunteers consumed a glucose beverage (GLU), a puffed wheat control bar (PWB), and a bar containing cross-linked RS4 (RS4XL) matched for available CHO content. The RS4XL peak glucose and insulin concentrations were lower than the GLU and PWB. The incremental AUC (iAUC) for glucose and insulin were lower following ingestion of RS4 compared with the GLU and PWB trials. RS is likely to become an increasingly attractive ingredient to many food manufacturers (particularly those of breads and cakes or similar products which traditionally may have had higher GI values) (Nugent, 2005).

Reader et al. (2002) demonstrated the glycemic and insulinemic response of subjects with type 2 diabetes after consumption of three energy bars. Subjects consumed approximately 50 g of CHO from one of the three snack bars: the nutrition bar with the RS; another energy nutrition bar with similar macronutrient composition that does not contain RS and a popular candy bar. The mean peak blood glucose level at 60 min for the RS bar (9.46 ± 0.33 mmol/L) was significantly lower than that of the traditional energy bar (11.25 ± 0.32 mmol/L), and the candy bar (11.03 ± 0.33 mmol/L). There was significant difference in insulin values at 90 min for the traditional energy bar (498 ± 55 pmol/L) vs. RS bar (288 ± 57 pmol/L) but not for the RS bar vs the candy bars (318 ± 58 pmol/L). An improved postprandial hyperglycemic peak is one of the main therapeutic targets in diabetic patients. Shin et al. (2007) have found that streptozotocin (STZ)-induced diabetic rats were divided into cornstarch (control) and high RS Japonica rice groups and were fed with 640 g starch/kg diets for 4 weeks. The area under the glucose curve of corn starch was 173.8 ± 6.9 and Japonica rice diet was 154.3 ± 8.7 mmol $\times$ min/L, and the area under the insulin curve of cornstarch was 12.9 ± 0.1 and Japonica rice diet was 12.0 ± 0.6 nmol $\times$ min/L. The glycosylated hemoglobin levels, serum fructosamine, and cholesterol concentrations in diabetic rats fed the Japonica rice diet were significantly lower than the control group.

Hypocholesterolemic Effects

Hypocholesterolemic effects of RS have been widely demonstrated. RS appears to particularly affect lipid metabolism, as seen from studies in rats, where reductions in a number of measures of lipid metabolism have been observed. These include total lipids, total cholesterol, low density lipoproteins (LDL), high density lipoproteins (HDL), very low density lipoproteins (VLDL), intermediate density lipoproteins (IDL), triglycerides, and triglyceride-rich lipoproteins (Nugent, 2005). In rats, RS diets (25% raw potato) markedly raised the cecal size and the cecal pool of SCFAs, as well as SCFA absorption and lowered plasma cholesterol and triglyceride levels. Also, there was a lower concentration of cholesterol in all lipoprotein fractions, especially, the HDL1 and a decreased concentration of triglycerides in the triglyceride rich lipoprotein fraction (Sajilata et al., 2006). From studies on hamsters fed diets containing cassava starch (CSH) extrudated with 9.9% oat fibre or CSH extruded with 9.7% RS, hypocholesterolemic properties of both were demonstrated suggesting their potential for use in foods to improve cardiovascular health (Martinez-Flores et al., 2004).

Fernandez et al. (2000) studied the effects of RS on the cholesterol metabolism in guinea pigs. The animals were fed cellulose (14 g/100 g) as control diets while the RS (10 g/l00 g) for a period of 4 weeks. Guinea pigs fed RS had 27% lower plasma cholesterol concentrations than the control group while plasma triacylglycerol levels did not differ. Studies in rats have demonstrated that the cholesterol and TAG lowering effects of RS can be partly explained by an increased production of volatile fatty acids in the cecum which after absorption results in reduced activities of the regulatory enzymes of fatty acid synthesis (Morand et al., 1994). Kim et al. (2003) demonstrated that RS from corn or rice at the level of 16% (w/w) could lower plasma cholesterol concentrations in diabetic rats. Additionally, RS decreased the elevated plasma lipid contents by diabetic condition. RS from rice was able to lower liver cholesterol contents. The decreased intestinal transit time was observed by feeding both types of RS.

One of the significant effects of resistant corn or rice starch is the lowering of serum cholesterol concentrations as shown in the present study. Martinez-Floresa et al., 2004 studied the serum and liver lipidemic responses in hamsters fed diets containing 2% cholesterol and different dietary fiber sources. The following diets were made from: (a) the control diet made from extruded CSH contained 9.3% cellulose, (b) CSH extruded with 9.7% RS (CS-RS), (c) CSH extruded with 9.9% oat fiber (CS-OF), and (d) the reference diet contained 9.5% cellulose, and no cholesterol was added.

Total cholesterol, LDL+VLDL-cholesterol and triglycerides were significantly lower in serum of hamsters fed on the CS-RS (17.87%, 62.92%, and 9.17%, respectively) and CS-OF (15.12%, 67.41%, and 18.35%, respectively) diets, as compared to hamster fed with the CSH diet. Similar results were found in the livers of hamsters fed on the CS-RS and CS-OF diets, as compared to hamsters fed with the CSH diet. Ranhotra et al. (1996) also found reduced values of LDL+VLDL-cholesterol serum in hamsters fed diets based on RS and cellulose. Diets containing fiber showed decreases of 32.4% (CS-RS diet) and 51.7% (CS-OF diet), as compared to the CSH diet. Reductions in LDL+VLDL-cholesterol are beneficial, reducing coronary heart disease risk. As a result of the increasing HDL-cholesterol

and lowering LDL+VLDL-cholesterol values, the ratio HDL-cholesterol/LDL+VLDL-cholesterol increased in diets containing fiber (2.05 for the CS-RS diet and 3.04 for the CS-OF diet). The CSH and control diets had ratios of 1.50 and 3.22, respectively.

Koo et al. (2010) used the corn starch which was chemically modified by cross-linking with sodium trimetaphosphate/sodium tripolyphosphate (99:1. w/w) and the physiological properties (in vitro and in vivo) of the cross-linked corn starch were investigated as a function of the degree of cross-linking. When mice were fed the diets containing the corn starch with low (Cross Linked Corn Starch-5) and high (Cross Linked Corn Starch -12) degree of cross-linking (51.3 and 99.1%, respectively), significant effects on the serum lipid, serum cholesterol, and total liver lipid value were observed. The serum total lipid value was significantly lower in the mice fed CLCS-5 (303.50 ± 22.20 mg/dL) and CLCS-12 (294.45 ± 17.65 mg/dL) diets than those fed the HFD diet (337.81 ± 8.19 mg/dL) while the serum total cholesterol levels were lower by 8.3% and 5.7% in the mice fed CLCS-5 and CLCS-12, as compared to the group fed HFD. Total liver lipid values were significantly lower in mice fed the CLCS-5 (79.47 ± 19.72 mg/g) and CLCS-12 (80.60 ± 8.81 mg/g) than those fed HFD (241.50 ± 15.65 mg/g).

DIETARY FIBER

Dietary fiber may be considered the "dinosaur" of functional foods. The American Association of Cereal Chemists (2001) proposed the following comprehensive definition: "dietary fiber is the edible parts of plants or analogous CHOs that are resistant to digestion and absorption in the human small intestine with complete or partial fermentation in the large intestine. Dietary fiber includes polysaccharides, oligosaccharides, lignin, and associated plant substances. Dietary fiber promotes beneficial physiological effects including laxation, and/or blood cholesterol attenuation, and/or blood glucose attenuation."

Insoluble and Soluble Dietary Fiber

Dietary fibers are typically classified according to various physico-chemical and physiological criteria including solubility, viscosity, and fermentability (James et al., 2003). Thus, it can be classified as either water soluble (pectins, gums, mucilages, algal polysaccharides, some storage polysaccharides, and some hemicelluloses) (Theuwissen et al., 2008). The structural or nonviscous fibers (lignins, cellulose, and some hemicelluloses) are water-insoluble. Water-insoluble fiber is responsible for increased stool bulk and help to regulate bowel movements. Generally, soluble fibers such as guar gum (GG), pectin, and psyllium are highly viscous and are readily fermented to SCFAs in the large bowel in comparison with insoluble fibers such as cellulose (James et al., 2003).

Furthermore, soluble fibers elicit a much more pronounced hypolipidemic and hypoglycaemic response than their insoluble counterparts (Fernandez, 2001). The hypolipidemic effects and cardioprotective benefits associated with dietary soluble fiber consumption are abundantly clear from the results of human clinical trials (Naumann et al., 2006), animal feeding studies (Venkatesan et al., 2007), epidemiological investigations and meta-analysis reports (Castro et al., 2005).The mean total daily fiber intake amongst adults in most industrialized countries is well below 25 g, the minimal amount recommended by various health organizations. Of total dietary fiber intake, approximately 20% is water-soluble and 80% is water-insoluble (Bazzano et al., 2003).

Guar Gum/Partially Hydrolyzed Guar Gum

GG is a galactomannan storage polysaccharide made up of polymers comprising about 10,000 molecules. It consists of a (1→4)-linked-β-D-mannopyranose backbone with (1→6)-linked-α-D-galactose side chains. It hydrates easily in cold water giving a highly viscous solution. GG is also used to treat constipation and to decrease serum cholesterol concentrations (Theuwissen et al., 2008). Because GG is extremely viscous, it is very difficult to incorporate it in food in large enough quantities to obtain a physiological effect, so an enzymatic hydrolyzate of GG (partially hydrolyzed GG, PHGG) is used in beverages. The PHGG is prepared by treatment of GG with beta-endogalactomannase from a strain of Aspergillus niger, and its average molecular mass measured by HPLC was 20,000 Daltons and functions as a soluble dietary fiber. PHGG as sold commercially is completely soluble, acid and heat stable, unaffected by ions, and will not gel at high concentrations.

Physiological Effects

Insulinotropic Effect

PHGG can delay the elevation of blood sugar and potentially control the blood sugar in the diabetic patients (Nandini et al., 2003). Based on these evidences, we implicate that PHGG had a potential in reduction of diabetes incidence. GG with viscous hydrocolloids may reduce the rate of gastric emptying and the diffusion of nutrients to the mucosa of the small intestine and increase cecal output. It was observed by Sierra et al. (2002) that consumption of 14 g/day of psyllium in twenty type 2 diabetic patients for 6 weeks resulted in reduction of total and LDL-cholesterol by 7% and 9%, respectively. Takahashi et al. (2009) reported that infusing PHGG @ 3 and 6 g/L into the duodenum of the rats would result in reduction of both postprandial plasma glucose and plasma insulin concentrations after 120 min than the control containing no PHGG. This may be due to the decrease in the rate of glucose diffusion from the small intestine luminal digesta of the rat.

Hypocholesterolemic Effects

Freitas et al., 2006 reported an increase in intestinal iron absorption in growing anemic rats which consumed PHGG (67.5%) in comparison to those fed on a diet with cellulose (35.4%) and without dietary fiber (31.3%). Tuohy et al., 2001 studied the prebiotic effect of biscuits containing partially hydrolyzed GG. In the study, 31 volunteers consumed daily either three experimental biscuits (providing a total (g/day) of 6.6 FOS and 3.4 PHGG) or three placebo biscuits for two 21-days crossover periods. Bifidobacteria significantly increased in number on ingestion of the experimental biscuits compared with pretreatment and placebo population levels. It has been shown that PHGG has a positive effect on diarrhoea, e.g., reducing its duration or incidence, as well as having an ameliorating effect in human subjects suffering from constipation.

Total serum cholesterol was reduced by a diet with PHGG compared with the controlled diet period, while other serum lipid parameters were unaffected during the study. Several reports have indicated that PHGG like GG efficiently increases bile acid secretion and leads to a cholesterol-lowering effect in rats fed high-fat diet (Minekus et al., 2005). Kuo et al., 2009 have reported that dietary supplementation with PHGG in hamsters fed with high-fat diet reduced plasma cholesterol and lipid profiles and increased antioxidant Bcl-2 and HSP-70 protein expression in the vessels. High dose of PHGG was more potent than low dose of PHGG in all these effects. The study further demonstrated that PHGG inhibit FeCl3 enhanced oxidative stress and ICAM-1 expression and delay arterial thrombus formation in hamsters fed with high-fat diet. Intake of 3–6% PHGG decreases the bioaccessibility of both fat and cholesterol through the depletion flocculation mechanism to inhibit bile salt induced emulsification and decreases lipolytic activity in the healthy volunteers (Minekus et al., 2005). PHGG supplement decreased cholesterol and lipid levels and oxidative stress and thus has a potential to prevent hypertension and cardiovascular diseases (Yamada et al., 2003). After 50 days of PHGG administration, attenuation of urinary protein excretion, total cholesterol level, and the morphological changes peculiar to diabetic nephropathy were observed in the rats.

Khan et al. (1981) observed a large reduction (25%) in LDL-cholesterol in 24 healthy volunteers receiving 9 g of GG per day for 4 weeks. Minekus et al. (2005) noticed the effect of PHGG on healthy volunteers after intake of a yoghurt drink containing 3–6% PHGG. The results showed that PHGG decreased the bioaccessibility of both fat and cholesterol in a dose-dependent manner. The bioaccessibility of fat was decreased from 79.4, 70.8, and 60.1 whereas of cholesterol was decreased from 82.2, 75.4, and 64.0.

Beta-glucans

Beta-glucans are glucose polymers that, unlike cellulose, have a branched structure enabling them to form viscous solutions. The food sources of beta-glucan includes major component of cell wall material in oats and barley while it is also present in small amounts in wheat (Gray, 2006). Some constituents of dietary fibre, particularly those from fruits and grains (e.g., GG, pectin, beta-glucan, and psyllium; so-called soluble fibres) can reduce blood cholesterol levels by altering cholesterol and bile acid absorption and by effects on hepatic lipoprotein production and cholesterol synthesis (Lunn and Buttriss 2007). Brunner et al. (2005) found that diets rich in oats (a source of beta-glucan) reduced LDL cholesterol by an average of 0.2 mmol/L compared with the control diet.

Trials have shown the beneficial effects of oat β-glucan on lipids to be mediated long term through bile acid binding and subsequent removal of cholesterol from circulation (Lia et al., 1995; Zhang et al., 1992). While postprandial trials also have shown acute glycaemia and insulinaemia to be blunted in the hours following intake of oat soluble fibre in healthy (Holm et al., 1992; Wood et al., 1994; Braaten et al., 1991) as well as diabetic (Tapola et al., 2005) subjects. This may be a consequence of the rapidly increased gastrointestinal viscosity that occurs following a soluble fibre meal (Wood et al., 1994), which in turn leads to a slower rate of digestion in the intestinal lumen and slower absorption of glucose into the portal and systemic circulation and a reduced demand for insulin (Slavin et al., 1999). Improved postprandial glucose control may in part explain the emerging role of soluble fibre in reduction of type II diabetes risk.

Insulinotropic Effects

A variety of fiber components, especially soluble fibers, have generally been reported to decrease glucose and insulin responses (Behall and Hallfrisch, 2002; Hallfrisch et al., 1995; Krezowski et al., 1987) in normoglycemic and diabetic subjects. Soluble fibers (found in oats, barley, and citrus fruits) are more effective in controlling glucose and insulin than predominantly insoluble fibers such as wheat (Behall and Hallfrisch, 2002, Wursch and Sunyer, 1997). Glucose and insulin responses were significantly lower after barley pasta containing 12 g β-glucan (Yokoyama et al., 1997) or barley bread (Liljeberg et al., 1996) than after wheat pasta or bread, respectively. Suggested mechanisms for these results include viscosity of the soluble fibers resulting in delayed or reduced CHO absorption from the gut (Battilana et al., 2001).

Wursch and Sunyer (1997) reported a 50% reduction in glycemic peak with a concentration of 10% β-glucan in a cereal food while anticipated a significant lowering of plasma LDL cholesterol with the daily consumption of $\geq$3 g of β-glucan. Behall et al. (2006) reported the decrease in glucose and insulin AUC when β-glucan (17 and 33%, respectively) or RS (24 and 38%, respectively) content was increased as compared with low β-glucan–low RS muffins. The greatest AUC reduction occurred after meals containing both high β-glucan–high RS (33 and 59% lower AUC for glucose and insulin, respectively). Poppitt et al. (2007) investigated the postprandial effect of a highly enriched barley β-glucan product on blood glucose, insulin, and lipids when given along with a high-CHO food. A 10 g dose of

barley β-glucan fibre supplement containing 6.31 g β-glucan was added to high-CHO food. Hence, β-glucan supplement addition significantly blunted the glycaemic and insulinaemic responses on the food. Hinata et al. (2007) also observed dramatic decrease in fasting plasma glucose levels with diet of cooked rice and barley mixture (7:3 ratios) containing 18.7 g/day soluble fiber in diabetic male prisoners.

Thondre and Henry (2009) fortified the unleavened Indian flat breads (chapatis) with barley β-glucan and evaluated the glycemic response. The incremental area under the glucose curve of chapatis containing 4 and 8 g β-glucan were significantly lower than control chapatis. The GI values of chapatis with 4 and 8 g β-glucan were 43% to 47% lower (GI, 30 and 29, respectively) compared with chapatis without β-glucan (GI, 54). The barley β-glucan significantly reduces GI of chapatis, particularly at doses of 4 and 8 g per serving. Dong et al. (2011) reported that the oat β-glucan could regulate the glucose metabolism in STZ-induced diabetic mice and inhibit the activities of intestinal disaccharides in the diabetic mice and in vitro.

Nondigestible Oligosaccharides

Nondigestible oligosaccharides (NDOs) comprising 3 to 10 sugar units occur naturally in plants consumed as foods, mainly vegetables, cereals, and nuts. Can also be made chemically or enzymatically from mono or disaccharides or by enzyme hydrolysis of polysaccharides. Because they are nondigested, they exhibit similar physical effects to their larger polysaccharide counterparts. They are typically fermentable and some have prebiotic properties (e.g., fructans such as FOS obtained from inulins with a degree of polymerisation of 3–60 and synthetic analogues synthesized from sucrose). Physiological properties have been confirmed for some NDOs and these are primarily mediated via change to the gut microflora (either composition or activity) (Gray, 2006). Onions, chicory, and Jerusalem artichokes are the major dietary sources. Currently, use in food of FOS and galacto-oligosaccharides is permitted in most European countries. [(There has been recent discussion about the degree of polymerisation considered necessary to justify inclusion in the fibre definition. In the current proposal from the European Commission, only saccharides with three or more units are included, there being a concern about laxative effects with smaller molecules) (Gray, 2006)]. The main physiological effects of NDOs are: source of SCFA, alter microflora balance (i.e., act as prebiotics), immunomodulatory role (reported improvements in gut barrier function against infection), increase calcium absorption, and possible role for prebiotics in cancer protection (Nugent, 2005; Cummings and Stephen, 2007; Elia and Cummings, 2007).

CONCLUSION

Dietary management aimed to attain optimal nutrition and to prevent several potential health complications associated with the diabetes. Dietary interventions suggested the use of constituent sources specifically for the diabetes specific formulae to improve glycaemic control. Dietary products designed using a variety of substances including complex CHOs (dietary fibres and RSes), protein, peptides, ketoacids, bioactive peptides, MUFA, PUFA, antioxidant vitamins, minerals, and prebiotics to become functional. Consequently, providing the health implications due to several physiological effects such as insulinotropic, hypocholesterolemic, antihypertensive, etc. resulting in reduce onset risk or symptoms of metabolic syndrome associated with diabetes.

REFERENCES

AACC. American Assn. of Cereal Chemists (2001). Approved methods of the AACC. 10th ed. Method 44-15A. Minn. AACC, St. Paul.

Aggarwal, R. A. K. and Kansal, V. K. (1991). The influence of skim milk on plasma lipids, lipoproteins and lecithin: cholesterol acyltransferase activity in cholesterol fed rabbits. *Milchwissenschaft*. **46**:335–337.

Aggarwal, R. A. K. and Kansal, V. K. (1993). Effect of skim milk in regression of plasma lipids and sudanophilic lesions on rabbits having induced atherosclerosis. *Ind. J. Dairy Sci*. **46**:104–109.

AHA (2007). Guidelines for the Management of Patients with Unstable Angina/Non–ST-Elevation Myocardial Infarction. *J. Am. College Cardiol*. **50**:1–157.

American Diabetes Association (2006). Nutrition recommendations and interventions for diabetes. *Diabetes Care*. **29**:2140–57.

American Heart Association (1990). The cholesterol facts. A summary of evidence relating dietary fats, serum cholesterol and coronary heart disease. A joint Statement by the American heart Association and National Heart, Lung and Blood Institute. *Circulation*. **81**:1721–1733.

Andlauer, W. and Fürst, P. (2002). Nutraceuticals: a piece of history, present status and outlook. *Food Res. Int*. **35**:171–176

Anette, D., Larsen, M. T., Mu, Huiling, Hermansen, K., Stender, S. and Astrup, A. (2008). Comparison of 3 ad libitum diets for weight-loss maintenance, risk of cardiovascular disease, and diabetes: a 6-mo randomized, controlled trial. *Am. J. Clin. Nutr.* **88**:1232–1241.

Augustine, M. A., Clarke, P. T. and Craven, H. (2003). Characteristics of milk powders. **In**: Encyclopedia of Food Sciences and Nutrition, Vol. 7, 2nd ed., pp. 4710. Academic Press. Elsevier Science. Ltd. Oxford.

Azen, S. P., Dajun Q., Wendy J. M., Sevanian, A., Selzer, R. H., Liu, Chao-Ran, Liu, Ci-Hua and Hodis, H. N. (1996). Effect of supplementary antioxidant vitamin intake on carotid arterial wall intima-media thickness in a controlled clinical trial of cholesterol lowering. *Circulation*. **94**:2369–2372.

Baghurst, K. I., Baghurst, P. A., and Record, S. J. (2001). Dietary fibre, nonstarch polysaccharide and resistant starch intakes in Australia. **In**: Handbook of dietary fibre in human health, pp. 583–591. Spiller, G. A., Ed., CRC Press, Boca Raton, FL.

Bantle, J. P., Wylie-Rosett, J., Albright, A. L., Apovian, C. M., Clark, N. G. and Franz, M. J. (2006). Nutrition recommendations and interventions for diabetes: a position statement of the American Diabetes Association. *Diabetes Care*. **29**:2140–2157.

Battilana, P., Ornstein, K., Minehira, K., Schwarz, J. M., Acheson, K., Schneiter, P., Burri, J., Jequier, E. and Tappy, L. (2001). Mechanisms of action of β-glucan in postprandial glucose metabolism in healthy men. *Eur. J. Clin. Nutr.* **55**:327–333.

Bazzano, L. A., He, J., Ogden, L. G., Loria, C. M. and Whelton, P. K. (2003). Dietary fiber intake and reduced risk of coronary heart disease in US men and women: the National Health and Nutrition Examination Survey I Epidemiologic Follow-up Study. *Arch. Intern. Med.* **163**:1897–1904.

Behall, K. M. and Hallfrisch, J. (2002). Effects of grains on glucose and insulin responses. **In**: Whole-Grain Foods in Health and Disease, pp. 269–282. Marquart, L., Slavin, J. L., Fulcher, R. G., Eds., American Association Cereal Chemists, St. Paul, MN.

Behall, K. M., Scholfield, D. J. Hallfrisch, J. G. and Liljeberg-Elmstahl, H. G. M. (2006). Consumption of both resistant starch and β-glucan improves postprandial plasma glucose and insulin in women. *Diabetes Care*. **29**(5):976–981

Belobrajdic, D. P., McIntosh, G. H. and Owens, J. A. (2004). A high-whey-protein diet reduces body weight gain and alters insulin sensitivity relative to red meat in Wistar rats. *J. Nutr.* **134**(6):1454–1458.

Berry, E. M., Eisenberg, R. and Haratz, D. (1991). Effects of diets rich in monounsaturated fatty acids on plasma lipoproteins-the Jerusalem Nutrition Study: high MUFAs vs high PUFAs. *Am. J. Clin. Nutr.* **53**:899–907.

Bhatia, E. and Kansal, V. K. (2011). Dairy Ghee opposed to soyabean oil attenuates diet induced hypercholesterolemic in rats. *Milchwissenschaft*. **65**:15–18.

Braaten, J. T., Wood, P. J., Scott, F. W., Riedel, K. D., Poste, L. and WCollins, M. (1991). Oat gum lowers glucose and insulin after and oral glucose load. *Am. J. Clin. Nutr.* **53**:1425–1430.

Brunner, E. J., Thorogood, M. and Rees, K. (2005) Dietary advice for reducing cardiovascular risk. *Cochrane Database Syst. Rev.* 4: Art. No: CD002128. DOI: 10.1002/.

Brynes, A. E., Edwards, C. M., Jadhav, A., Ghatei, M. A., Bloom, S. R. and Frost, G. S. (2000). Diet-induced change in fatty acid composition of plasma triacylglycerols is not associated with change in glucagon-like peptide 1 or insulin sensitivity in people with type 2 diabetes. *Am. J. Clin. Nutr.* **72**:1111–1118.

Bounous, G. and Molson, J. H. (2003). The antioxidant system. *Anticancer Research*. **23**(2B):1411–1415.

Buse, J. B., Polonsky, K. S. and Burant, C. F. (2003). Type 2 Diabetes Mellitus. **In**: Williams Textbook of Endocrinology, 10th ed., p. 1457. Larsen, P. R., Kronenberg, H. M., Melmed, S. and Polonsky, K. S., (Eds.), (Saunders, Philadelphia.

Calbet, J. A. and MacLean, D. A. (2002). Plasma glucagon and insulin responses depend upon the rate of appearance of amino acids after ingestion of different protein solutions in Humans. *J. Nutr.* **132**(8):2174–2182.

Castro, I. A., Barroso, L. P. and Sinnecker, P. (2005). Functional foods for coronary heart disease risk reduction: a meta-analysis using a multivariate approach. *Am. J. Clin. Nutr.* **82**:32–40.

Chiasson, J. L., Josse, R. G., Gomis, R., Hanefeld, M., Karasik, A. and Laakso, M. (2002). Acarbose for prevention of type 2 diabetes mellitus: the STOP-NIDDM randomised trial. *The Lancet*. **359**:2072–2077.

Christinsen, E., Schnider, S., Palmvig, B., Tauber-Lassen, E. and Pedersen, O. (1997). Intake of a diet high in trans monounsaturated fatty acids or saturated fatty acids: effects on postprandial insulinemia and glycemia in obese patients with NIDDM. *Diabetes Care*. **20**(5):881–887.

Cummings, J. H., Beatty, E. R., Kingman, S. M., Bingham, S. A. and Englyst, H. N. (1996). Digestion and physiological properties of resistant starch in the human large bowel. *Br. J. Nutr.* **75**:733–747.

Cummings, J. H., Edmond, L. M. and Magee, E. A. (2004). Dietary carbohydrates and health: Do we still need the fibre concept? *Clin. Nutr. supplements*. **1**:5–17.

Cummings, J. H. and Stephen, A. M. (2007) Carbohydrate terminology and classification. *Eur. J. Clin. Nutr.* **61**(Suppl. 1):5–18.

DeFelice, S. L. (1992). The nutraceutical initiative: a recommendation for U.S. Economic and regulatory reforms. *Genet. Eng. New*. **12**:13–15.

Dong, J., Cai, F., Shen, R. and Liu, Y. (2011). Hypoglycaemic effects and inhibitory effect on intestinal disaccharides of oat beta-glucan in streptozotocin-induced diabetic mice. *Food Chem*. **129**(3):1066–1071.

Due, A., Larsen, T. M., Mu, H., Hermansen, K., Stender, S. and Astrup, A. (2008). Comparison of 3 ad libitum diets for weight-loss maintenance, risk of cardiovascular disease, and diabetes: a 6-mo randomized, controlled trial. *Am. J. Clin. Nutr*. **88**(5):1232–1241.

Dyssler, P. and Hoffmann, D. (1994). Estimation of resistant starch intake in Europe. **In**: Proceedings of the concluding plenary meeting of EURESTA, pp. 84–86. Asp, N.-G., van Amelsvoort, J. M. M., and Hautvast, J. G. A. J., Eds., Wageningen, The Netherlands, EURESTA.

Eilat Adar, Sigal, J. X., Zephier, E., O'Leary, V., Howard, B. and Resnic, H. E. (2008). Adherence to dietary recommendations for saturated fat, fiber, and sodium is low in American Indians and other U.S. adults with diabetes. *J. Nutr.* **138**:1699–1704.

Elia, M. and Cummings, J. H. (2007) Physiological aspects of energy metabolism and gastrointestinal effects of carbohydrates. *Eur. J. Clin. Nutr.* **61**(Suppl. 1):40–74.

Englyst, K. N., Englyst, H. N., Hudson, G. J., Cole, T. J. and Cummings, J. H. (1999). Rapidly available glucose in food: An invitro measurement that reflects the glycemic response. *Am. J. Clin. Nutr.* **69**:448–454.

Fernandez, M. L. (2001). Soluble fiber and indigestible carbohydrate effects on plasma lipids and cardiovascular risks. *Curr. Opin. Lipidol*. **12**: 35–40.

Fernandez, M. L., Roy, S. and Vergara-Jimenez, M. (2000). Resistant starch and cholestyramine have distinct effects on hepatic cholesterol metabolism in guinea pigs fed a hypercholesterolemic diet. *Nutr. Res*. **20**(6):837–849.

Fuentes-Zaragoza, E., Riquelme-Navarrete, M. J., Sanchez-Zapata, E. and Perez-Alvarez, J. A. (2010). Resistant starch as functional ingredient: A review. *Food Res. Int*. **43**:931–942.

Fitz-Gerald, R. J. and Meisel, H. (2003). Milk protein hydrolysis and bioactive peptides. **In**: Advanced Dairy Chemistry, 3rd ed., part B, pp. 675–698. Fox, P. F. and McSweeney, P., Eds., Kluwer Academic/Plenum Publishers, New York.

Freitas, De cassia. K., Silverio Amancio, O. M., Ferrreira Novo, N., Fagundes-Neto, U. and Batista De Morais, M. (2006). Partially hydrolyzed guar gum increases intestinal absorption of iron in growing rats with iron deficiency anemia. *Clin. Nutr.* **25**(5):851–858.

Frid, A. H., Nilsson, M., Holst, J. and Bjorck, M. E. (2005). Effect of whey on blood glucose and insulin responses to composite breakfast and lunch meals in type 2 diabetic subjects. *Am. J. Clin. Nutr.* **82**:69–75.

Gannon, M. C., Nuttall, F. Q., Krezowski, P. A., Billington, C. J. and Parker, S. (1986). The serum insulin and plasma glucose responses to milk and fruit products in type 2 (noninsulin- dependent) diabetic patients. *Diabetologia*. **29**:784–91.

Gannon, M. C., Nuttall, F. Q., Lane, J. T. and Burmeister, L. A. (1992). Metabolic response to cottage cheese or egg white protein, with or without glucose, in type II diabetic subjects. *Metabolism*. **41**:1137–45.

Gannon, M. C., Nuttall, F. Q., Neil, B. J. and Westphal, S. A. (1988). The insulin and glucose responses to meals of glucose plus various proteins in type II diabetic subjects. *Metabolism*. **37**:1081–1088.

Garg, A., Bonanome, A., Grundy, S. M., Zhang, Z. J. and Unger, R. H. (1988). Comparison of a high-carbohydrate diet with a high-monounsaturated-fat diet in patients with noninsulin- dependent diabetes mellitus. *N Engl J. Med*. **319**:829–834.

Gill, H. S., Doull, F., Rutherfurd, K. J. and Cross, M. L. (2000). Immunoregulatory peptides in bovine milk. *Br. J. Nutr.* **84**(Suppl. 1):S111–S117.

Golay, A., Ferrara, J. M., Felber, J. P. and Schneider, H. (1990). Cholesterol-lowering effect of skim milk from immunized cows in hypercholesterolemic patients. *Am. J. Clin. Nutr.* **52**:1014–1019.

Gray, J. (2006). Dietary Fibre: Definition, Analysis, Physiology and Health. International Life Sciences Institute, Brussels.

Gunnarsson, P. T., Winzell, M. S., Deacon, C. F., Larsen, M. O. Jelic, K., Carr, R. D. and Ahren, B. (2006). Glucose induced incretin hormone release and inactivation are differentially modulated by oral fat and protein in mice. *Endocrinology*. **147**(7):3173–3180.

Hallfrisch, J., Scholfield, D. J. and Behall, K. M. (1995). Diets containing soluble oat extracts improve glucose and insulin responses of moderately hypercholesterolemic men and women. *Am. J. Clin. Nutr.* **61**: 379–384.

Harper, W. J. (2001) Biological Properties of Whey Components. A Review. The American Dairy Products Institute, Chicago, IL

Harper, C. R. and Jacobson, T. A. (2001). The fats of life: The role of omega-3 fatty acids in the prevention of coronary heart disease. *Arch. Intern. Med*. **161**:2185–2192.

Hathcock, J. (2001). Dietary Supplements: How They Are Used and Regulated. *J. Nutr.* **131**:1114S–1117S.

Health (2002). Hypertension prevalence among adults, according to age, race, sex and Hispanic origin. *National Centre for Health Statistics*. Table **68**:210. http://www.cdc.gov/nchs/fastats/hypertens.html.

Higgins, J. A. (2004). Resistant starch: Metabolic effects and potential health benefits. *J. AOAC Int*. **87**(3):761–768.

Hinata, M., Ono, M., Midorikawa, S. and Nakanishi, K. (2007). Metabolic improvement of male prisoners with type 2 diabetes in Fukushima Prison, Japan. *Diabetes Res. Clin. Pract*. **77**:327–32.

Holm, J., Koellreutter, B. and Wursch, P. (1992). Influence of sterilization, drying and oat bran enrichment of pasta on glucose and insulin responses in healthy subjects and on rate and extent of in vitro starch digestion. *Eur. J. Clin. Nutr.* **46**:629–640.

ICMR, (2005). Guidelines for management of Type 2 Diabetes. World Health Organization Workshop. Indian Council of Medical Research. 2–4 May, 2003.

James, S. L., Muir, J. G. and.Curtis, S. L. (2003). Dietary fiber: a roughage guide. *Intern. Med. J*. **33**:291–296.

Jeffrey, I. M. (2005). The rational use of dietary supplements and nutraceuticals in clinical medicine. *Mt Sinai J. Med*. **72**:3.

Jenkins, D. J. A., Jerkins, A. L., Kendall, C. W. C., Augustine, L. and Vuksan, V. (2001). Dietary fiber, carbohydrate metabolism, and chronic disease. **In**: Advanced dietary fiber technology, pp. 162–167. McCleary, B. V. and Prosky, L., Eds., Iowa State University Press, Ames, IA.

Joannic, J. L., Auboiron, S., Raison, J., Basdevant, A., Bornet, F. and Guy-Grand, B. (1997). How the degree of unsaturation of dietary fatty acids influences the glucose and insulin responses to different carbohydrates in mixed meals. *Am. J. Clin. Nutr.* **65**:1427–1433.

Kalra, K. E. (2003). Neutraceutical – definition and introduction. *A.A.P.S. PharmSci*. **5**:3.

Kansal, V. K. (2010). Health benefits of Desi ghee. *Indian Dairyman*. November:60–63.

Katyal, I. 1992. Dietary management of diabetes. *Int. J. Diabetes*. **12**:139–140.

Kaushik, D. and Kaushik, N. (2009). Functional Food / Nutraceuticals regulation in India. Pharmainfo_net.htm. **7**(5).

Keys, A., Anderson, J. T. and Grande, F. (1965). Serum cholesterol response to changes in the diet. IV. Particular saturated fatty acids in the diet. *Metabolism*. **14**:776–787.

Keys, A., Menotti, A. and Karvonen, J. M. (1986). The diet and 15-year death rate in the Seven Countries Study. *Am. J. Epidemiol*. **124**:903–915.

Khan, A. R., Khan, G. Y. and Mitchel, A. (1981). Effect of guar gum on blood lipids. *Am. J. Clin. Nutr.* **34**:2446–2449.

Kim, K. W., Chunga, M. K., Kangb, N. E., Kimc, M. H. and Parkd, O. K. (2003). Effect of resistant starch from corn or rice on glucose control, colonic events, and blood lipid concentrations in streptozotocin-induced diabetic rats. *J. Nutr. Biochem.* **14**:166–172.

Koo, S. H., Lee, K. Y. and Lee, H. G. (2010). Effect of cross-linking on the physicochemical and physiological properties of corn starch. *Food Hydrocolloids*. **24**:619–625.

Korhonen, H. and Pihlanto-Leppala, A. (2006). Bioactive peptides: Production and functionality. *Int. Dairy J*. **16**(9):945–960.

Krezowski, P. A., Nuttall, F. Q., Gannon, M. C., Billington, G. J. and Parker, S. (1987). Insulin and glucose responses to various starch-containing foods in type II diabetic subjects. *Diabetes Care*. **10**:205–212.

Kris-Etherton, P. M. and Shaomei, Y. (1997). Individual fatty acid effects on plasma lipid and lipoproteins: human studies. *Am. J. Clin. Nutr.* **65**(Suppl):1628S–1644S.

Kuo, Dar-Chih, Hsu, Shih-Ping and Chien, Chiang-Ting. (2009). Partially hydrolyzed guar gum supplement reduces high-fat diet increased blood lipids and oxidative stress and ameliorates FeCl3-induced acute arterial injury in hamsters. *J. Biomed. Sci*. **16**:15

Lada, A. T. and Rudel, L. L. (2003). Dietary monounsaturated versus polyunsaturated fatty acids: which is really better for protection from coronary heart disease? *Curr. Opin. Lipidol*. **14**:41–46.

Lawton, C. L., Delargy, H. J., Brockman, J., Smith, F. C. and Blundell, J. E. (2000). The degree of saturation of fatty acids influences post-ingestive satiety. *Br. J. Nutr.* **83**:473–482.

Lia, A., Hallmans, G., Sandberg, A. S., Sundberg, B., Åman, P. and Andersson, H. (1995). Oat β-glucan increases bile acid excretion and a fiber-rich barley fraction increases cholesterol excretion in ileostomy subjects. *Am. J. Clin. Nutr.* **62**:1245–1251.

Liljeberg, H. G. M., Granfeldt, Y. E. and Bjorck, I. M. E. (1996). Products based on a high fiber barley genotype, but not on common barley or oats, lower postprandial glucose and insulin responses in healthy humans. *J. Nutr.* **126**:458–466.

Lunn, J. and Buttriss, J. L. (2007). Carbohydrates and dietary fibre. *Nutr. Bull*. **32**:21–64.

Mandal, S. (2007). Nutraceuticals and diabetes – an update. *Pharmbit*. **16**(2):101–103.

Marshall, K. (2004). Therapeutic applications of whey protein. *Altern. Med. Rev.* **9**(2):136–156.

Martinez-Floresa, H. E., Changb, Y. K., Martinez-Bustosc, F. and Sgarbier, V. (2004). Effect of high fiber products on blood lipids and lipoproteins in hamsters. *Nutr. Res*. **24**:85–93.

Matthews, D. E. (2005). Observations of branched chain amino acid administration in humans. *J. Nutr.*. **135**(6):S1580–S1584.

Mayer-Davis, E. J., Monaco, J. H. and Hoen, H. M. (1997). Dietary fat and insulin sensitivity in a triethnic population: the role of obesity – The Insulin Resistance Atherosclerosis Study (IRAS). *Am. J. Clin. Nutr.* **65**:79–87.

Mensink, R. P. and Katan, M. B. (1989). Effect of a diet enriched with monounsaturated or polyunsaturated fatty acids on levels of low-density and high-density lipoprotein cholesterol in healthy women and men. *N. Engl. J. Med*. **321**:436–41.

Minekus, M., Jelier, M. and Xiao, J. Z, (2005). A fibre cocktail of fenugreek,guar gum and wheat bran reduces oxidative modification of LDL induced by an atherogenic diet in rats. *Mol. Cell. Biochem*. **294**:145–153.

Morand, C., Levrat, M. A., Besson, C., Demigne, C. and Remesy, C. (1994). Effects of a diet rich in resistant starch on hepatic lipid metabolism in rat. *J. Nutr. Biochem*. **5**:138–144.

Nagaraju, A. and Belur, L. R. (2008). Rats fed blended oils containing coconut oil with groundnut oil or olive oil showed an enhanced activity of hepatic antioxidant enzymes and a reduction in LDL oxidation. *Food Chem*. **108**:950–957.

Nandini, C. D., Sambaiah, K. and Salimath, P. V. (2003). Dietary fibres ameliorate decreased synthesis of heparan sulphate in streptozotocin induced diabetic rats. *J. Nutr. Biochem*. **14**(4):203–210.

Nathan, D. M., Buse, J. B., Davidson, M. B., Heine, R. J., Holman, R. R. and Sherwin, R. (2006) Management of hyperglycemia in type 2 diabetes: a consensus algorithm for the initiation and adjustment of therapy: a consensus statement from the American Diabetes Association and the European Association for the Study of Diabetes. *Diabetes Care*. **29**:1963–1972.

Naumann, E., van Rees, A. B. and Onning, G. (2006). Beta-glucan incorporated into a fruit drink effectively lowers serum LDL-cholesterol concentrations. *Am. J. Clin. Nutr.* **83**:601–605.

Nilsson, M., Stenberg, M., Frid, A. H., Holst, J. J. and Bjorck, I. M. E. (2004). Glycemia and insulinemia in healthy subjects after lactose equivalent meals of milk and other food proteins: the role of plasma amino acids and incretins. *Am. J. Clin. Nutr.* **80**:1246–1253.

Nugent, A. P. (2005). Health properties of resistant starch. British Nutrition Foundation, *Nutr. Bull*. **30**:27–54.

Ostman, E. M., Elmstahl, H. G. M. L. and Bjorck, I. M. E. (2001). Inconsistency between glycemic and insulinemic responses to regular and fermented milk products. *Am. J. Clin. Nutr.* **74**:96–100.

Parillo, M., Rivellese, A. A., Ciardullo, A. V., Capaldo, B., Giacco, A., Genovese, S. and Riccardi, G. (1992). A high-monounsaturated-fat/low-carbohydrate diet improves peripheral insulin sensitivity in non-insulin-dependent diabetic patients. *Metabolism*. **41**(12):1373–1378.

Pelkman, C. L., Fishell, V. K., Maddox, D. H., Pearson, T. A., Mauger, D. T. and Kris-Etherton, P. M. (2004). Effects of moderate-fat (from monounsaturated fat) and low-fat weightloss diets on the serum lipid profile in overweight and obese men and women. *Am. J. Clin. Nutr.* **79**:204–212.

Perera, A., Meda, V. and Tyler, R. T. (2010). Resistant starch: A review of analytical protocols for determining resistant starch and of factors affecting the resistant starch content of foods. *Food Res. Int*. **43**(8):1959–1974.

Pfeuffer, M. and Schrezenmeir, J. (2007). Milk and the metabolic syndrome. *Obesity Rev*. **8**(2):109–118.

Poppitt, S. D., Van Drunen, J. D., McGill, A. T., Mulvey, T. B. and Leahy, F. E. (2007). Supplementation of a high-carbohydrate breakfast with

barley β-glucan improves postprandial glycaemic response for meals but not beverages. *Asia Pac. J. Clin. Nutr.* **16**(1):16–24.

Raben, A., Andersen, K. and Karberg, M. A. (1997). Acetylation of or beta-cyclodextrin addition to potato starch: Beneficial effect on glucose metabolism and appetite sensations. *Am. J. Clin. Nutr.* **66**:304–314.

Rabinowitz, D., Merimee, T. J., Maffezzoli, R. and Burgess, J. A. (1966). Patterns of hormonal release after glucose, protein and glucose plus protein. *Lancet*. **2**:454–456.

Ramesh, B., Saravanan, R. and Pugalendi, K. V. (2006). Effect of dietary substitution of groundnut oil on blood glucose, lipid profile, and redox status in streptozotocin diabetic rats. *Yale J. Biol. Med.* **79**:9–17.

Ramesh, B., Saravanan, R. and Pugalendi, K. V. (2005). Influence of sesame oil on blood glucose, lipid peroxidation and antioxidants' status in streptozotocin diabetic rats. *J. Med. Food.* **8**:378–381.

Ranhotra, G. S., Gelroth, J. A. and Glaser, B. K. (1996). Effect of resistant starch on blood and liver lipids in hamsters. *Cereal Chem.* **73**:176–178.

Rasmussen, O. W., Thomsen, C., Hansen, K. W., Vesterlund, M., Winter, E. and Hermansen, K. (1993). Effects on blood pressure, glucose, and lipid levels of a highmonounsaturated fat diet compared with a high-carbohydrate diet in NIDDM subjects. *Diabetes Care*. **16**:1565–1571.

Ratnayake, W. S. and Jackson, D. S. (2008). Thermal behavior of resistant starches RS 2, RS 3, and RS 4. *J. Food Sci.* **73**(5):356–366.

Reader, D., Connell, B. S. O., Johnson, M. L. and Franz, M. (2002). Glycemic and Insulinemic response of subjects with type 2 diabetes after consumption of three energy bars. *J. Am. Dietetic Assoc.* Aug. **102**:8.

Reader, D., Johnson, M. L., Hollander, P. and Franz, M. (1997). Response of resistant starch in a food bar vs. two commercially available bars in persons with type II diabetes mellitus. *Diabetes*. **46**(1):254.

Richardson, T. (1978). The hypocholesterolemic effect of milk- a review. *J. Food Prot.* **41**:226–235.

Riserus, U., Willett, W. C. and Hu, F. B. (2009). Dietary fats and prevention of type 2 diabetes. *Prog. Lipid Res.* **48**(1):44–51.

Roberfroid, M. B. (2000). Prebiotics and probiotics: Are they functional foods? *Am. J. Clin. Nutr.* **71**(6):1682–1687.

Sajilata, M. G., Singhal, R. S. and Kulkarni, P. R. (2006). Resistant starch – A review. *Compr. Rev. Food Sci. Food Saf.* **5**:1–17.

Salmeron, J., Frank, B. H., Manson, J. E., Stampfer, M. J., Colditz, G. A., Rimm, E. B. and Walter, C. W. (2001). Dietary fat intake and risk of type 2 diabetes in women. *Am. J. Clin. Nutr.* **73**:1019–1026.

Scholz-Ahrens, E., Ade, P., Marten, B., Weber, P., Timm, W. and Yahya, A. (2007). Prebiotics, probiotics, and synbiotics affect mineral absorption, bone mineral content, and bone structure. *J. Nutr.* **137**:838–846.

Sener, A. and Malaisse, W. J. (1980). L-Leucine and a nonmetabolized analogue activate pancreatic islet glutamate dehydrogenase. *Nature*. **288**:187–189.

Sharma, A., Yadav, B. S. and Ritika, B. Y. (2008). Resistant starch: Physiological roles and food applications. *Food Rev. Int.* **24**:193–234.

Shin S. I., Lee C. J., Kim, Dae-Ik, Lee, H. A., Cheong, J. J., Chung, K. M., Baik, M. Y., Park, C. S., Kim, C. H. and Moon, T. W. (2007). Formation, characterization and glucose response in mice to rice starch with low digestibility produced by citric acid treatement. *J. Cereal Sci.* **45**(1):24–33

Sierra, M., Garcia, J. J. and Fernandez, N. (2002). Therapeutic effects of psyllium in type 2 diabetic patients. *Eur. J. Clin. Nutr.* **56**:830–842.

Sinha, K. (2009). By 2010, India will have maximum no. of diabetics. TNN, Oct 21, 2009 Times of India.

Slavin, J. L., Martini, M. C., Jacobs Jr, D. R. and Marquat, L. (1999). Plausible mechanisms for the protectiveness of whole grains. *Am. J. Clin. Nutr.* **70**(Suppl):459S–463S.

Sloan, A. E. (2006). Top ten functional food trends. *Food Technol.* **60**(4):22–40.

Stettler, C., Allemann, S., Juni, P., Cull, C. A., Holman, R. R. and Egger, M. (2006). Glycemic control and macrovascular disease in types 1 and 2 diabetes mellitus: meta-analysis of randomized trials. *Am. Heart J.* **152**:27–38.

Susan, J van Dijk, Edith, JM Feskens, Marieke, B Bos, Dianne, WM Hoelen, Rik, Heijligenberg, Mechteld, Grootte Bromhaar, Lisette, CPGM de Groot, Jeanne, HM de Vries, Michael, Muller and Lydia, A Afman. (2009). A saturated fatty acid–rich diet induces an obesity-linked proinflammatory gene expression profile in adipose tissue of subjects at risk of metabolic syndrome. *Am. J. Clin. Nutr.* **90**(6):1656–1664.

Takahashi, T., Yokawab, T., Ishiharab, N., Okubob, T., Chub, D. C., Nishigakia, E., Kawadaa, Y., Katoa, M. and Junejab, L. R. (2009). Hydrolyzed guar gum decreases postprandial blood glucose and glucose absorption in the rat small intestine. *Nutr. Res.* **29**(6):419–425.

Tamimi, E. K. A., Seib, P. A., Snyder, B. S. and Haub, M. D. (2010). Consumption of Cross- Linked Resistant Starch (RS4XL) on Glucose and Insulin Responses in Humans. *J. Nutr. Metab.* **201**:1–6.

Tanasescu, M., Eunyoung, C., Manson, J. E. and Frank, B. H. (2004). Dietary fat and cholesterol and the risk of cardiovascular disease among women with type 2 diabetes. *Am. J. Clin. Nutr.* **79**:999–1005.

Tapola, N., Karvonen, H., Niskanen, L., Mikola, M. and Sarkkinen, E. (2005). Glycemic responses of oat bran products in type 2 diabetic patients. *Nutr. Metab. Cardiovasc. Dis.* **15**:255–261.

Tharanathan, R. N. (2002). Food-derived carbohydrates: Structural complexity and functional diversity. *Crit. Rev. Biotechnol.* **22**(1):65–84.

Thondre, P. S. and Henry, C. J. K. (2009). High-molecular weight barley glucan in chapatis (unleavened Indian flatbread) lowers glycemic index. *Nutr. Res.* **29**(7):480–486.

USDA. (August 1997). The USDA Nutrient Database for Standard Reference. USDA, Washington, D.C.

Theuwissen, E., Ronald, P. and Mensink. (2008). Water-soluble dietary fibers and cardiovascular disease. *Physiol. Behavior.* **94**:285–292.

Thompson, L. U., Jenkins, D. J. A., Vic Amer., Reichert, R., Jenkins, A. and Kamuisky, J. (1982). The effect of fermented and unfermented milks on serum cholesterol. *Am. J. Clin. Nutr.* **36**(12):1106–1111.

Thomsen, C., Rasmussen, O., Lousen, T., Holst, J. J., Fenselau, S., Schrezenmeir, J. and Hermansen, K. (1999). Differential effects of saturated and monounsaturated fatty acids on postprandial lipemia and incretin responses in healthy subjects. *Am. J. Clin. Nutr.* **69**(6):1135–1143.

Topping, D. L., Anthony, M. F. and Bird, F. (2003). Resistant starch as prebiotic and synbiotic: State of the art. *Proc. Nutr. Soc.* **62**:171–176.

Trecroci, D. (2005). Whey proteins may increase insulin secretion and improve blood glucose control Swedish researchers contend. *Am. J. Clin. Nutr.* **1**(6):1124–1128.

Tuohy, K. M., Kolida1, S., Lustenberger, A. M. and Gibson, G. R. (2001). The prebiotic effects of biscuits containing partially hydrolysed guar gum and fructo-oligosaccharides – a human volunteer study. *Br. J. Nutr.* **86**: 341–348.

Venkatesan, N., Devaraj, S. N. and Devaraj, H. (2007). A fibre cocktail of fenugreek, guar gum and wheat bran reduces oxidative modification of LDL induced by an atherogenic diet in rats. *Mol. Cell. Biochem.* **294**: 145–153.

Vessby, B., Unsitupa, M., Hermansen, K., Riccardi, G., Rivellese, A. A., Tapsell, L. C., Nalsen, C., Berglund, L., Louheranta, A., Rasmussen, B. M., Calvert, G. D., Maffetone, A., Pedersen, E., Gustafsson, I. B. and Storlien, L. H. (2001). Substituting dietary saturated for monounsaturated fat impairs insulin sensitivity in healthy men and women: The KANWU Study. *Diabetologia*. **44**(3):312–319.

Vilsboll, T., Knop, F. K. and Krarup, T. (2003). The pathophysiology of diabetes involves a defective amplification of the late-phase insulin response to glucose by glucose dependent insulinotropic polypeptide-regardless of etiology and phenotype. *J. Clin. Endocrinol. Metab Metab.* **88**:4897–4903.

Wahrburg, U., Martin, H., Sandkamp, M., Schulte, H. and Assmann, G. (1992). Comparative effects of a recommended lipid-lowering diet vs a diet rich in monounsaturated fatty acids on serum lipid profiles in healthy young adults. *Am. J. Clin. Nutr.* **56**:678–683.

Walzem, R. L., Dillard, C. J. and German, J. B. (2002). Whey components: millennia of evolution create functionalities for mammalian nutrition: What we know and what we may be overlooking. *Crit. Rev. Food Sci. Nutr.* **42**(4):353–375.

Wardlaw, G. M., Snook, J. T., Lin, M. C., Puangco, M. A. and Kwon, J. S. (1991). Serum lipid and apolipoprotein concentrations in healthy men on diets enriched in either canola oil or safflower oil. *Am. J. Clin. Nutr.* **54**:104–110.

Warensjo, E., Jansson, J. H. and Cederholm, T. (2010). Biomarkers of milk fat and the risk of myocardial infarction in men and women: a prospective, matched case control study. *Am. J. Clin. Nutr.* **92**:194–202.

Warren, J. M., Henry, C. J. K. and Simonite, V. (2003). Low glycemic index breakfast and reduced food intake in preadolescent child. *Pediatrics*. **112**:E414–E419.

Westphal, S., Kastner, S., Taneva, E., Leodolter, A., Dierkes, J. and Luley, C. (2004). Postprandial lipid and carbohydrate responses after the ingestion of a casein-enriched mixed meal. *Am. J. Clin. Nutr.* **80**: 284–290.

Woo, K. and Seib, P. A. (2002). Cross-linked resistant starch: Preparation and properties. *Cereal Chem*. **79**:819–825.

Wood, P. J., Braaten, J. T., Scott, F. W., Riedel, K. D., Wolynetz, M. S. and Collins, M. W. (1994) Effect of dose and modification of viscous properties of oat gum on plasma glucose and insulin following an oral glucose load. *Br. J. Nutr.* **72**:731–743.

Wrick, K. L. (1995). Consumer issues and expectations for functional foods. *Crit. Rev. Food Sci. Nutr.* **35**:167–173.

Wursch, P. and Sunyer, F. X. (1997). The role of viscous soluble fiber in the metabolic control of diabetes. *Diabetes Care*. **20**:1774–1780.

Xiao, R., Carter, J. A., Linz, A. L., Ferguson, M., Badger, T. M. and Simmen, F. A. (2006). Dietary whey protein lowers serum C- peptide concentration and duodenal SREBP-1c mRNA abundance, and reduces occurrence of duodenal tumors and colon aberrant crypt foci in azoxymethane-treated male rats. *J. Nutr. Biochem*. **17**(9):626–634.

Yamada, K., Tokunaga, Y., Ikeda, A., Ohkura, K., Kaku-Ohkura, S., Mamiya, S., Lim, B. O. and Tachibana, H. (2003). Effect of dietary fiber on the lipid metabolism and immune function of aged Sprague-Dawley rats. *Biosci. Biotechnol. Biochem*. **67**:429–433.

Yokoyama, J., Someya, Y., Yoshihara, R. and Ishii, H. (2008). Effects of high-monounsaturated fatty acid enteral formula versus high-carbohydrate enteral formula on plasma glucose concentration and insulin secretion in healthy individuals and diabetic patients. *J. Int. Med. Res*. **36**(1):137–146.

Yokoyama, W. H., Hudson, C. A., Knuckles, B. E., Chiu, M. C. M., Sayre, R. N., Turnlund, J. R. and Schneeman, B. O. (1997). Effect of barley beta-glucan in durum wheat pasta on human glycemic response. *Cereal Chem*. **74**:293–296.

Zhang, J. X., Hallmans, G., Andersson, H., Bosaeus, I., Aman, P., Tidehag, P., Stenling, R. and Lundin, E. (1992). Effect of oat bran on plasma cholesterol and bile acid excretion in nine subjects with ileiostomies. *Am. J. Clin. Nutr.* **56**:99–105.