*Review Article*

# Impact of quality of dietary fat on serum cholesterol and coronary heart disease: Focus on plant sterols and other non-glyceride components

GHAFOORUNISSA


**ABSTRACT**

Elevated serum low density lipoprotein (LDL) cholesterol is a strong risk factor for coronary heart disease; dietary as well as therapeutic regimens target reduction of serum LDL cholesterol to decrease the morbidity and mortality of coronary heart disease. The fatty acid composition of dietary fat has a marked impact on serum LDL cholesterol and other risk factors of diet-related chronic diseases (metabolic syndrome, diabetes and coronary heart disease). Besides fatty acids, which constitute >95% of their content, fats in foods contain other fat-soluble chemicals collectively called non-glyceride components. Sterols are a major part of the non-glyceride components of fats in plant foods and get concentrated in vegetable oils. Current evidence suggests that properly solubilized plant sterols or stanols incorporated in ester or free form in various food formulations effectively restrict the absorption of both dietary and biliary cholesterol causing 10%–14% reduction in serum LDL cholesterol in normal, hyperlipidaemic and diabetic subjects. The carotenoid-lowering effect of foods enriched with plant sterols can be corrected by increasing the intake of foods rich in carotenoids. The use of foods enriched with plant sterols as a part of a heart-healthy diet is recommended only after consulting a clinician. Recent studies strongly suggest that even smaller amounts of sterols available from natural plant foods and vegetable oils are important dietary components for lowering serum LDL cholesterol. Furthermore, some of the other non-glyceride components of food fats have one or more of the following functions—vitamin activity, serum LDL cholesterol-lowering and antioxidant activity. Since the hypocholesterolaemic and antioxidant effects of a combination of the non-glyceride components may be more than their individual effects, increasing dietary plant sterols and non-glyceride components from natural plant foods and vegetable oils could provide an additional dietary means for prevention/correction of dyslipidaemia and increasing the antioxidant potential of human diets. The food-based dietary guidelines recommended to ensure an optimal fat quality in the diet of Indians provide high levels of natural plant sterols and other health-promoting non-glyceride components in addition to adequate absolute levels of individual fatty acids and their optimal balance. National policies to promote these dietary guidelines may contribute to the prevention of coronary heart disease and other diet-related chronic diseases.


Natl Med J India 2009;22:126–32

## INTRODUCTION

Cardiovascular disease (coronary heart disease and stroke) is a leading cause of morbidity and mortality in both developed and developing countries.[1,2] The pathophysiological processes involved are mediated through effects on lipoprotein metabolism, thrombosis, blood pressure, arrhythmogenesis and inflammation. The disturbances in lipoprotein metabolism are reflected in elevated serum levels of total and low density lipoprotein (LDL) cholesterol, oxidized LDL, apoB and lipoprotein(a); low levels of high density lipoprotein (HDL) cholesterol and apoA. Metabolic syndrome (visceral obesity, insulin resistance, hypertension and dyslipidaemia), a strong risk factor for coronary heart disease (CHD) and type 2 diabetes, is widely prevalent in Indians.[3] The dyslipidaemia associated with the metabolic syndrome is characterized by elevated serum triglycerides, apoB, LDL cholesterol, oxidized LDL and sd (small dense) LDL cholesterol; and low apoA and HDL cholesterol. Studies on experimental animals as well as clinical trials, and metabolic and epidemiological studies in diverse human populations have documented a strong and consistent relationship between dietary fats (lipids) and risk factors of diet-related chronic diseases, particularly CHD.

## DIETARY FATS, SERUM LIPIDS AND CHD: CURRENT CONCEPTS

Dietary fats (lipids) are important components of the human diet, providing energy, essential fatty acids (linoleic acid [LA] and alpha-linolenic acid [ALA]) and serve as a source of fat-soluble vitamins. Since the mid-1960s, diets providing low saturated fatty acids (SFA), cholesterol and high polyunsaturated fatty acids (PUFA) have been recommended to reduce serum cholesterol and

Formerly Department of Biochemistry, National Institute of Nutrition, Jamai Osmania, Hyderabad, Andhra Pradesh, India

Correspondence to Flat #402, Maphar Comfortek, Shantinagar, Masabtank, Hyderabad 500028, Andhra Pradesh, India; *drghafoor2000@yahoo.com*

prevent CHD. In the 1980s and early 1990s, nutrition recommendations for the prevention of CHD called for a reduction of total fat in the diet through the substitution of carbohydrate for fat. But, recent studies suggest that low fat and high carbohydrate diets do not favourably affect serum lipids, glucose and insulin.[4–6] Conversely, consistent associations have been found between higher intake of specific dietary fat such as those rich in LA, long chain (LC) n-3 PUFA (eicosapentaenoic acid [EPA] and docosahexaenoic acid [DHA]), possibly ALA and lower risk of CHD.[1,2,6–8] Hence, optimal intakes of these fatty acids may be compromised on low fat diets. While substituting carbohydrates for SFA is of little benefit, substituting PUFA for either carbohydrates or SFA has favourable effects on serum lipids and CHD risk. The cholesterol-raising properties of SFA are attributed to lauric (12:0), myristic (14:0) and palmitic (16:0) acids.[9] Dietary cholesterol increases the LDL cholesterol-raising effects of SFA whereas PUFA offset the negative impact of dietary cholesterol because LA increases the removal of serum LDL cholesterol.[9] Trans-fatty acids (TFA) obtained from partially hydrogenated vegetable oils (PHVO) increase serum LDL cholesterol (effect similar to SFA), decrease HDL cholesterol (effect different from SFA) and increase the total cholesterol/HDL cholesterol ratio (powerful predictor of increased risk of CHD). Therefore, diets providing TFA increase the risk of CHD to a greater extent than SFA.[10] In view of the competitive interactions between the metabolism of LA and ALA to their respective LC n-6 PUFA (dihomogamma-linolenic acid [DGLA] and arachidonic acid [AA]) and LC n-3 PUFA (EPA and DHA) and subsequent formation of eicosanoids of '2' and '3' series, an adequate intake of both LA and ALA and their balance is important for physiological functions—lipoprotein transport, blood clotting, inflammation, immune functions and blood pressure regulation.[11,12] The LC n-3 PUFA provided from fish/fish oils lower serum triglycerides and have several health benefits through multiple mechanisms.[11,12]

## NON-GLYCERIDE COMPONENTS IN FATS

Besides fatty acids that exist as triacylglycerides (mono- and diacylglycerides exist as minor components) and complex lipids which account for >95% of the total mass, the unsaponifiable fraction of food lipids contains a wide range of non-glyceride components (NGC; Table I). The NGC contribute to the characteristic flavour and taste of fats and oils. The NGC of animal foods contain fat-soluble vitamins and cholesterol whereas plant foods have a number of different chemical compounds.[13] The levels and composition of NGC in plant foods and oils depend on the conditions under which the crops are grown as well as the maturity of the plants (grain, fruit and oilseed, etc.). Crude oils are refined so as to remove/minimize the levels of compounds which are undesirable for cooking quality and also those that are toxic for human health with a minimum possible loss of components beneficial for nutrition and health. Hence, several of the NGC present in crude oils from oil-bearing seeds, nuts or fruits may be destroyed, reduced in concentration or chemically modified during the steps normally used in the refining process. Plant sterols constitute the largest NGC of vegetable oils. Tocols (tocopherols and tocotrienols), carotenes and flavour compounds constitute a minor fraction. Since the 1950s, the nutritional and health importance of the unsaponifiable fraction was associated with only its fat-soluble vitamins and cholesterol. The tocopherols and other antioxidants in oils have been known to prevent oxidative deterioration of the oil during storage and heating.[13,14] However, during the past 2 decades some of the other NGC of fats in foods have been shown to have health-promoting and disease-preventing effects.[15] This review focuses on the LDL cholesterol-lowering effects of plant sterols, contribution of naturally occurring plant sterols in enhancing the health-protective role of plant foods and vegetable oils, and clinical/intervention studies on the efficacy and safety of plant sterol-enriched foods. It also includes a brief overview of the health-promoting role of other NGC of food fats.

TABLE I. Non-glyceride components in food fats and vegetable oils

| Group | Individual components |
|---|---|
| Natural hydrocarbons | Squalene, short and long chain hydrocarbons, waxes |
| Sterols | Plant sterols and cholesterol |
| Alcohols | Aliphatic and triterpene alcohols |
| Tocols | Tocopherols and tocotrienols |
| Phenolic compounds | Saponin, gossypol, phenolic acids |
| Carotenoids | Beta and other carotenes |
| Sulphur and nitrogen compounds | Isothiocyanates |
| Complex lipids | Phospholipids, sphingosine, diacylglyceride ethers, glucolipids |
| Unique compounds | Ubiquionones, lignans, flavonoids |

## PLANT STEROLS

### *Chemistry*

Plant sterols are plant compounds with a chemical structure and biological functions akin to cholesterol. They play a critical role in stabilizing the phospholipid bilayer in plant cell membrane just as cholesterol does in animal cell membrane. Plant sterols fall into one of three categories, viz. 4-desmethylsterol (cholestane series), 4-monomethylsterols (4-methylcholestane series) and 4, 4-dimethylsterols (lanostane series, i.e. triterpene alcohols). In plants, more than 40 sterols have been identified of which campesterol, b-sitosterol and stigmasterol are the most abundant. These 3 sterols are structurally similar to cholesterol (they are all 4-desmethyl sterols) and differ only in a side chain substitution of a methyl group (campesterol) or an ethyl group (sitosterol) or an ethylidine group (5-avenasterol) and a diene at C-22 (stigmasterol).[16,17] A less abundant class of related compounds found in plants is the stanols. These are completely saturated forms of sterols and lack the carbon–carbon double bonds found in cholesterol and sterols. Plant sterols (and stanols) exist in 4 different forms: as free alcohol, fatty acid esters, and conjugates with sugar moieties or phenolic acids.[16,17] The sterol pattern of vegetable oil is used to characterize and detect adulteration (sitosterol). However, nutrition research has focused mainly on 5 types—campesterol, b-sitosterol, stigmasterol, campestanol and b-sitostanol.

### *Modulation of cholesterol metabolism by plant sterols*

Cholesterol metabolism is regulated mainly in the small intestine and the liver.[18] Free cholesterol originating from bile and sloughed intestinal cells and diet (cholesteryl esters are hydrolysed to free cholesterol) is incorporated into mixed micelles—'packages' that deliver mixtures of lipids (including fat-soluble vitamins and carotenoids) for absorption into the mucosal cells. The intracellular trafficking of cholesterol involves passage through the epithelial brush border membrane, re-esterification in the mucosal cell and assembly into chylomicrons before secretion into the lymph. The process is regulated by ATP-binding cassette ABCG5 and ABCG8 transporters. The absorption of cholesterol varies from 30% to 80%.[19] The amount of plant sterols in food is an important modulator of cholesterol absorption.

The human body does not synthesize plant sterols endogenously. Akin to cholesterol esters, dietary plant sterol and stanol esters are hydrolysed to free sterols and stanols, respectively, and solubilized in mixed micelles. In general, only 0.1%–5% of the ingested plant sterols (depending on the type) are absorbed;[20] consequently, blood levels of plant sterols in humans are only 0.1%–0.14% of cholesterol levels.[17] The poor efficiency of absorption of plant sterols and stanols is attributed to the ABCG5 and ABCG8 transporter in enterocytes which selectively pump plant sterols and stanols from the enterocytes into the intestinal lumen, poor solubility of the sterols in mixed micelles, and the poor efficiency of intestinal cells to re-esterify the absorbed sterols.[17,21–23]

Plant sterols block both biliary and dietary cholesterol absorption in the intestine. Different mechanisms such as inhibition of pancreatic cholesterol esterase, competition for sterol uptake transporters, ACAT (acyl coenzyme A: cholesterol acyltransferase) inhibition, competition of plant sterols and stanols with cholesterol for the limited space in mixed micelles (solubilization), and co-crystallization with cholesterol to form insoluble mixed crystals are believed to contribute to a decrease in the absorption of cholesterol.[21–23] The net result is reduced intestinal absorption and less cholesterol reaching the liver via chylomicron remnants (Fig. 1).[23] In response to the decreased supply of exogenous cholesterol, receptor-mediated uptake of lipoprotein cholesterol is increased, resulting in reduction of serum LDL cholesterol levels.[22]

*Naturally occurring plant sterols in foods*

Plant sterols and stanols occur naturally in almost all vegetable foods; the content and composition vary widely.[24–33] Generally, the sterol distribution is typical for each plant family and is not significantly changed by plant selection/hybridization. The total sterol content in selected foods is given in Table II. Nuts and oilseeds have higher amounts of plant sterols than other foods. Corn and sorghum have higher plant sterol content than rice and wheat. Whole wheat and brown rice are better sources of plant sterols than refined flour and polished rice, respectively. Legumes contain moderate levels. The plant sterol content of fresh vegetables and fruits is 2–20 mg/100 g and 10–32 mg/100 g, respectively. Mustard, fenugreek and cloves contain higher amounts of plant sterols than other spices. Plant sterols get concentrated in the unsaponifiable fraction of vegetable oils and constitute the largest NGC (Table III).[31–33] In most vegetable oils, the total sterol content is 200–370 mg/100 g (olive, groundnut, safflower, sunflower, soyabean, cottonseed). Rice bran, corn, mustard/rapeseed and sesame oils contain high levels (740–1156 mg/100 g), whereas palm oil and coconut oil contain low levels (88–110 mg/100 g). The major sterols are b-sitosterol, campesterol and stigmasterol. Brassicasterol, characteristic of the cruciferae family, is present in rapeseed and mustard seed oils but is in trace amounts in other oils. Plant stanols are present in smaller quantities in many of the above foods. Sterols are heat stable molecules. Cooking does not

TABLE II. Biological effects of non-glyceride components in vegetable oils

| Non-glyceride component | Oil | Biological effects | Mechanism of action |
|---|---|---|---|
| Plant sterols | All vegetable oils | Hypocholesterolaemic | Inhibits cholesterol absorption |
| Tocopherols | All vegetable oils | Vitamin and antioxidant | Scavenge reactive oxygen species (ROS) |
| Tocotrienols | Palm, rice bran | Vitamin and antioxidant | Scavenge ROS |
| Carotenes | Red palm | Provitamin A and antioxidant | Scavenge ROS |
| Oryzanols | Rice bran | Hypocholesterolaemic | Inhibits cholesterol biosynthesis |
| Hydroxytyrosol, phenolic acids | Olive | Antioxidant | – |
| Sesamin | Sesame | Hypocholesterolaemic; increases DGLA and eicosanoids of 1 series; anti-inflammatory | Inhibits cholesterol absorption and biosynthesis; inhibits $D^5$ desaturase activity |
| Sesamolin, sesamol | Sesame | Antioxidant | Potentiates antioxidant effects of tocopherols |

DGLA dihomogamma-linolenic acid

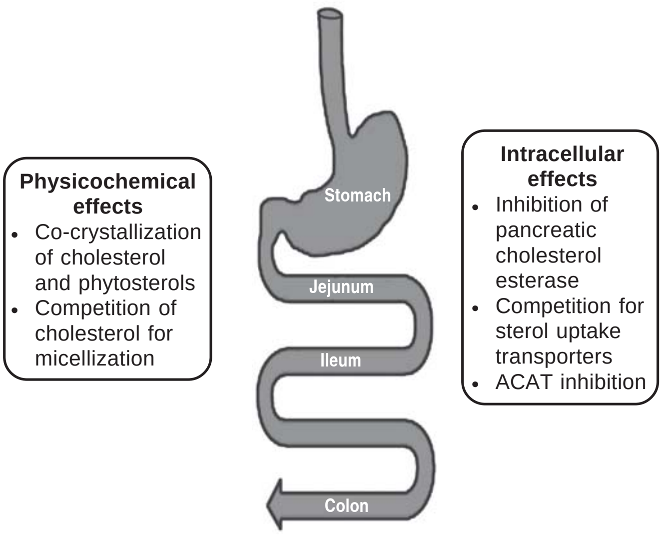


FIG 1. Probable mechanisms by which sterols might lower cholesterol absorption (adapted from Trautwein and Demonty[23]) ACAT acyl-coenzyme A: cholesterol acyltransferase

TABLE III. Sterol content of selected plant foods

| Food | Total sterols (mg/100 g) | Food | Total sterols (mg/100 g) |
|---|---|---|---|
| *Cereals* | | *Nuts/oilseeds* | |
| Wheat | 60,[26] 78[24] | Almond | 208,[25] 142[23] |
| Rice | 25[26] | Cashew | 150,[25] 160[23] |
| Oats | 58[26] | Coconut | 133,[26] 45[23] |
| Corn | 178[26] | Pistachios | 110,[23] 297[25] |
| Sorghum | 178[26] | Sesame | 711,[23] 714[26] |
| Rice bran | 1325[26] | Walnut | 108,[26] 110,[23] 128[25] |
| Wheat germ | 1970[26] | Peanuts | 137, 116,[25] 221[23] |
| Wheat bran | 200 | *Spices (dry)* | |
| *Legumes/Pulses* | | Mustard | 246[28] |
| Chick pea | 35[26] | Clove | 256[29] |
| Soyabean | 161[26] | Coriander | 46[26] |
| Beans | 76[26] | Cardamom | 46[26] |
| Broad beans | 124[26] | Cummin | 50[26] |
| Vegetables* | 2–20[26,27] | Fenugreek | 150[26] |
| Fruits† | 10–32[26,27,29] | Turmeric | 100[26] |

* tomato, carrot, lettuce, onion, spinach, pumpkin, cabbage, cauliflower, turnip, radish, beet root, cucumber † watermelon, pineapple, fig, banana, pear, grape, orange, pomegranate, strawberry, lemon

affect the plant sterol content of cereals, legumes and vegetables but industrial processing of vegetable oils results in 20%–70% loss.[31–33] The early human diet was probably rich in plant sterols, providing up to 1 g per day. However, most current western diets provide 200–400 mg/day of plant sterols.[16,17]

*Serum cholesterol-lowering effect of natural plant sterols*

Studies in humans have documented an inverse relationship between intake of plant sterols and both serum total and LDL cholesterol (corrected for age, body mass index and energy intake, dietary fibre and saturated fat).[34] Consumption of wheat germ (328 mg plant sterols) reduced cholesterol absorption by 42.8% compared with plant sterol-free wheat germ in human subjects.[35] Recent well controlled studies in both normal[36,37] and ileostomy[38] subjects have shown that differences in the cholesterol absorption or serum cholesterol-lowering effect of vegetable oil is partly due to plant sterol contents in oils (not entirely explained by its fatty acid composition). A study comparing purified corn oil triglycerides with or without corn oil plant sterols reported that in a single test meal, cholesterol absorption increased 38% with corn oil devoid of plant sterols. The effect was attributed to natural corn oil plant sterols because adding back 150 or 300 mg plant sterol to a test meal reduced cholesterol absorption by ~12% and 27.9%, respectively.[37] The sterols in rice bran oil are present as a component of γ-oryzanol (group of esters of phenolic acids with sterols, ferulate esters of triterpene alcohols and ferulate esters of β-sitosterol and campesterol), free sterols, and 4, 4'-dimethylsterols (cycloartenol and 24-methylene cycloartanol). Animal and human studies have shown that rice bran oil reduces serum total and LDL cholesterol and triglycerides, and increases serum HDL cholesterol concentrations.[39–42] In human studies, 300 mg of γ-oryzanol/day reduced LDL cholesterol[40] and consumption of margarine containing 2.1 g/day of plant sterols from rice bran oil for 3 weeks reduced serum LDL cholesterol by 9%.[42] These findings suggest that sterols in foods and vegetable oils are important dietary components for lowering serum LDL cholesterol.

*Plant sterol-enriched foods*

In the 1950s, plant sterols (β-sitosterol) were used as a drug (10–15 g/day) for hypercholesterolaemic patients.[16,17] These dosages were well tolerated and provided effective treatment for periods up to 5 years or more. However, because, large amounts were required for therapeutic effects (due to poor solubility and bioavailability) and the subsequent introduction of more effective cholesterol-lowering agents (statins), the pharmaceutical use of plant sterols was discontinued. The discovery that esterification of plant sterols and stanols with fatty acids or emulsification with phospholipids increases their solubility stimulated research on the development of several plant steryl and stanyl ester-enriched food formulations.[16,17] Steryl esters are made by esterifying plant sterols derived from vegetable oils with food-grade fatty acids. Steryl esters are simpler and cheaper to synthesize than stanyl esters because no hydrogenation is required. The composition of steryl (and stanyl) esters depends on their vegetable oil source and is frequently a mixture of β-sitosterol, campesterol, stigmasterol and other minor constituents. The fat-soluble nature of these sterols render margarine one of the best vehicles and margarines were the first plant sterol (stanol)-containing foods which were introduced commercially.[16,17] These have been shown to effectively reduce total and LDL cholesterol in normocholesterolaemic, hypercholesterolaemic and diabetic individuals in different populations independent of their background diets.[43–48] A meta-analysis of 41 randomized double-blind intervention trials showed that a daily intake of ~2 g plant sterol or stanol esters lower plasma LDL cholesterol by ~10% but triglycerides or HDL cholesterol were not affected and increasing the dose beyond 2 g/day provided no additional benefits.[43] Sterols and stanols are equally effective whether used in the esterified or unesterified form. In a double-blind, placebo-controlled trial over 1 year in healthy normocholesterolaemic and mildly hypercholesterolaemic volunteers, daily consumption of ~20 g spread enriched with ~1.6 g plant sterols showed a sustained cholesterol-lowering effect.[45,46] Although plant sterol-enriched foods do not affect HDL cholesterol and triglyceride concentrations in either diabetic patients or in men with the metabolic syndrome,[47,48] the decrease in total and LDL cholesterol itself would contribute to reducing the elevated risk of cardiovascular disease in these patients. Plant sterols can be emulsified with lecithin and incorporated in low-fat foods (yoghurts, low-fat milk) and these have been shown to reduce serum cholesterol in hypercholesterolaemic subjects.[49] In healthy human volunteers a reduced-calorie orange juice beverage containing plant sterols effectively lowered C reactive protein concentrations suggesting that plant sterols may be anti-inflammatory.[50] However, in patients on statin therapy sterol or stanol consumption for 16 weeks did not affect markers of antioxidant status, oxidative stress, endothelial dysfunction and low-grade inflammation.[51] In a recent study, fish oil fatty acid esters of plant sterols resulted in lower serum triglycerides and plasminogen activator inhibitor (PAI)-1 concentrations, and higher fat-soluble vitamin levels in comparison with sunflower oil or olive oil fatty acid esters of plant sterols.[52] These findings suggest that fish oil fatty acid esters of plant sterols may offer people with hyperlipidaemia a more comprehensive lipid-lowering approach. A study of Indian adults with mild hyperlipidaemia showed that a once daily intake of 2 g plant sterols in a yoghurt drink, 2 g fish oil LC n-3 PUFA/day in capsules, and their combination had beneficial effects on the lipid profile.[53]

The 3-hydroxy-3-methylglutaryl coenzyme A reductase inhibitors (statins), agents that lower endogenous cholesterol synthesis, are used for treating patients with hypercholesterolaemia. Studies have shown that the addition of plant sterol ester-supplemented margarine to statin therapy offers LDL cholesterol reduction equivalent to doubling the dose of statin.[54]

*Safety aspects of plant sterol-enriched foods.* Since the absolute serum levels of either plant sterols or stanols with a 2–3 g oral dose of plant sterols do not exceed the normal range (0.29–1.7 g/100 ml), in both normal persons and those with hypercholesterolaemia, and doses up to 3 g/day in both short term and long term studies (up to 1 year) provided no evidence of toxic effects, the use of foods fortified with plant sterols is considered safe in adults.[45–47] Plant sterols lower compounds which are transported by lipoproteins (α-carotene, β-carotene, lycopene and α-tocopherol) but not vitamins A (retinol), D and K.[44–46] In trials testing plant sterol doses of ~1.5 g/day, the magnitude of reduction in plasma concentrations were: α-carotene ~9%, β-carotene 28%, lycopene 7% and α-tocopherol ~8%. However, normalization of the plasma concentration of these vitamins with respect to LDL cholesterol concentration shows significantly lower concentrations of only β-carotene (8%–19%). Studies have shown that an additional serving of fruits and vegetables rich in carotenoids is effective in maintaining blood carotenoid concentrations.[44–46] Sitosterolaemia is a rare autosomal recessive disorder which results from absorption of high plant sterols and their impaired biliary elimination. Patients with sitosterolaemia develop tendon xanthomatosis and CHD at a young age. Hence, such patients should be counselled against the use of products fortified with plant sterols.[44–46] A recent study has shown that plant sterols accumulate in aortic valves and the mechanism of plant sterol deposition in stenotic valves is closely related to their levels in the circulation.[55] Therefore, prospective studies are warranted that evaluate not only their effects on cholesterol reduction, but also on clinical endpoints. Ratnayake and Vavasour[56] showed that an increase in cell membrane rigidity due to decrease in cholesterol/increase in plant sterol deposition in cell membranes promotes strokes and shortens the life span of stroke-prone spontaneously hypertensive (SHRSP) rats. These new dimensions are currently being studied.

## DIETARY FAT AND PLANT STEROLS FOR CARDIOVASCULAR HEALTH

The dietary recommendations for cardiovascular health target the metabolic syndrome and LDL cholesterol. Diets providing moderate fat (~30% E), low SFA (<8% E), minimal industrially produced TFA (<1% E TFA), ~10% E PUFA (LA 5–8, ALA 1–2 and 200 mg/day LC n-3 PUFA), up to 12% E MUFA (oleic acid 18:1 n-9), low cholesterol (<300 mg/day) and adequate natural antioxidants are advocated for reducing the risk of CHD.[1] To enhance reduction in LDL, the American Heart Association (AHA) and National Cholesterol Education Program Adult Treatment Panel III (NCEP ATP III) advocate, in addition to several dietary changes, an option to include plant sterol/stanol-enriched foods.[57] In September 2000, the US Food and Drugs Administration (FDA) authorized the use of a health claim for products containing plant sterol and stanol esters to reduce the risk of CHD.[58] In 2002, the FDA[59] approved the use of free-form sterols and stanols and extended the health claim to include a broader range of food products. Consequently, several commercial plant sterol-enriched foods are being marketed in many parts of the world. However, the use of plant sterol-enriched foods is recommended only in consultation with a clinician.[44–46,54,57–59] The recommended target market for plant sterol-enriched foods should include adults (non-pregnant and non-lactating women) with raised blood cholesterol concentrations and/or an increased risk of CHD. To correct the carotenoid-lowering effect of plant sterols, increased consumption of fruits and vegetables (including one or more carotenoid-rich source) is advocated. In the case of children with hypercholesterolaemia, fat-soluble vitamin status should be monitored and appropriately corrected.[45–47,57–59] However, the routine use of plant sterol-enriched foods to lower the risk of CHD by the general population is not advised.

## HEALTH-PROMOTING EFFECTS OF NGC OTHER THAN PLANT STEROLS

The health-promoting effects of NGC other than plant sterols are summarized in Table IV. The distribution of natural tocopherols (a, b, g, d) varies in different plant foods and oils both quantitatively and in the amount of different isomers.[14,31,60] Tocotrienols are found at relatively high concentrations in oils extracted from the fruit of the palm tree. Other sources include rice bran, wheat germ and barley.[14,31,60] Tocopherols and tocotrienols capture and destroy damaging oxy free radicals that possibly play a role in cellular ageing, atherosclerosis and cancer. The lignans (sesamin, sesamolin and sesamol) in sesame seed and oil have several nutritional and health effects. Studies in rats have shown that sesamin inhibits tocopherol metabolism, increases serum and tissue tocopherol levels and has hypolipidaemic effects.[60–64] The hypocholesterol-aemic effects of sesamin are due to inhibition of the micellar solubility of cholesterol resulting in a reduction in cholesterol absorption and inhibition of liver microsomal 3 hydroxy 3 methyl glutaryl CoA reductase. In a clinical study (*n*=12),[62] sesamin reduced serum total and LDL cholesterol. Sesame lignans in combination with tocopherols have higher hypocholesterolaemic and antioxidant effects compared with the effects of lignans, suggesting synergism in their biological effects.[61–64] Sesamin specifically inhibits $D^5$ desaturase activity, which leads to accumulation of DGLA, a precursor of 1 series eicosanoids and decreases the production of pro-inflammatory 2 series eicosanoids. These effects on PUFA and eicosanoid metabolism may contribute to the anti-inflammatory effects of sesame lignans in sesame seed and oil.[61–64] A group of derivatives of hydroxytyrosol present in olive oil are powerful antioxidants.[65] The above overview suggests that, apart from plant sterols, the other NGC of food fats and vegetable oils also provide a dietary means for prevention/correction of dyslipidaemia and increasing the antioxidant potential of human diets.

TABLE IV. Sterols, tocopherols and tocotrienols in vegetable oils (mg/100 g)

| Oil | Sterols | Sterols (Mean) | Toco-pherols* | Toco-trienols |
|---|---|---|---|---|
| Corn | 1700,[30] 952,[26] 978,[25] 965,[29] 1185[29] | 1156 | 78 | |
| Rice bran | 1161,[30] 1055[26] | 1108 | 115 | 45 |
| Sesame | 561,[30] 864,[26] 472,[25] 850[29] | 686 | 75 | |
| Rape/Mustard | 624,[30] 767,[26] 773,[25] 800 | 741 | 62 | |
| Cottonseed | 421,[30] 327,[26] 319[29] | 355 | 77 | |
| Soyabean | 335,[30] 221,[26] 349,[25] 248[29] | 288 | 95 | |
| Sunflower | 297,[30] 436[25] | 366 | 54 | |
| Safflower | 257,[30] 440[29] | 348 | 80 | |
| Groundnut | 210,[30] 206,[26] 315,[25] 205[29] | 234 | 36 | — |
| Olive oil | 212, 232,[26] 177,[25] 220[29] | 210 | 10 | — |
| Palm oil | 109,[30] 117,[26] 39[25] | 88 | 57 | 45 |
| Palm kernel oil | 140,[30] 95,[26] 92[29] | 109 | 1 | 2 |
| Coconut | 106,[30] 133,[26] 125,[25] 85[29] | 112 | 1 | 2 |

*contents vary depending on processing and refining methods

## OPTIMAL QUALITY OF FAT INTAKE: IMPLICATIONS FOR INDIANS

Fat intake in Indians is highly income-dependent and, for this reason, highly skewed. Taking into account the fat contributed from different ingredients of the Indian diet (invisible fats), the daily visible fat (vegetable oil, ghee and butter) requirements depending on the physiological status range between 20 and 50 g/person.[66] India has several kinds of vegetable oils. Mustard/rapeseed oil, soyabean oil, groundnut oil and palm oil constitute ~75% of the total vegetable oil consumption. Rice bran, cottonseed, sunflower, safflower, coconut, sesame and vanaspati are the other vegetable oils.[67] Since a complete dependence on just one vegetable oil does not ensure optimal intake of fatty acids and their balance for prevention of CHD (particularly LA, ALA and their balance), the use of a correct combination of 2 or more vegetable oils has been advocated.[60,66,68] Table V shows that some of the recommended oil combinations provide a greater variety of NGC which may have a health-promoting/disease-preventing role due to synergism in their hypocholesterolaemic and antioxidant effects.[61–64] The plant sterols in various oil combinations range between 188 and 924 mg/100 g oil. The use of (i) rice bran oil in combination with either soyabean oil or mustard/rapeseed oil or (ii) sesame oil in combination with mustard/rapeseed oil provide high levels of plant sterols (698–924 mg/100 g oil), and wider range of other

TABLE V. Non-glyceride components in the oil combinations recommended for Indians (mg/100 g oil)

| Oil combination (1:1) | Plant sterols | Tocopherols (Tocotrienol) | Unique health-promoting components |
|---|---|---|---|
| *Oil containing LA + Oil containing both LA and ALA* | | | |
| Mustard/Rapeseed + Groundnut | 487 | 49 | |
| Mustard/Rapeseed + Sesame* | 713 | 69 | Sesamin, sesamolin and sesamol |
| Mustard/Rapeseed + Rice bran* | 924 | 88 (22) | Oryzanol |
| Mustard/Rapeseed + Safflower + Palmolein | 356 | 57 (13) | |
| Mustard/Rapeseed + Sunflower + Palmolein | 352 | 49 (13) | |
| Mustard/Rapeseed + Cottonseed + Palmolein | 466 | 56 (13) | |
| Soyabean + Groundnut | 261 | 66 | |
| Soyabean + Sesame | 487 | 85 | Sesamin, sesamolin and sesamol |
| Soyabean + Rice bran* | 698 | 108 (22) | Oryzanol |
| Soyabean + Palm/Palmolein | 188 | 73 (22) | |
| *Oil containing high LA + Oil containing moderate or low LA* | | | |
| Sunflower + Palmolein | 227 | 54 (22) | |
| Safflower + Palmolein | 216 | 65 (22) | |
| Sunflower + Groundnut | 300 | 45 | |
| Safflower + Groundnut | 291 | 58 | |
| Sunflower + Sesame† | 526 | 64 | Sesamin, sesamolin and sesamol |
| Safflower + Sesame† | 517 | 77 | Sesamin, sesamolin and sesamol |
| Sunflower + Rice bran† | 737 | 87 (22) | Oryzanol |
| Safflower + Rice bran† | 568 | 97 (22) | Oryzanol |
| Sesame + Rice bran† | 897 | 98 (22) | Sesamin, sesamol, sesamolin, oryzanol |

* furnish linoleic acid (LA), a-linolenic acid (ALA) and their balance, tocopherols and high sterols plus unique components † tocopherols, high sterols plus unique components

health-promoting NGC in addition to ensuring adequate absolute levels of LA, ALA and their balance (n-6/n-3 ratio) in the total diet. Some oil combinations which lower LA but do not provide ALA, namely combination of either safflower oil or sunflower oil with either rice bran oil or sesame oil also provide high levels of plant sterols (517–897 mg/100 g oil) and a wide range of other health-promoting NGC. These computations reinforce our earlier recommendation to use a correct combination of 2 or more vegetable oils.[60,66,68] Ideally, blending of oils to maximize sterol intake naturally and derive benefits of NGC is important. However, hypercholesterolaemic patients have the option of incorporating sterol-enriched products as part of a healthy diet to ensure optimal intake of sterols to lower cholesterol, along with blending of oils which will provide the right profile of fatty acids.

To ensure adequate ALA and optimal LA/ALA balance from the dietary components other than vegetable oils, an increase in the intake of ALA-rich foods (wheat, pearl millet, pulses, green leafy vegetables, fenugreek, flaxseed, mustard seeds) has been recommended.[59,65,67] Apart from providing fibre and micronutrients, these foods furnish appreciable levels of plant sterols (Table II). The recommendation to substitute part of the visible and invisible fat from animal foods with whole nuts[60,69] would elicit beneficial effects due to plant sterols (Table II) and other NGC in addition to their recognized benefits[69] due to (i) fatty acid balance (decrease SFA and increase MUFA and PUFA), (ii) micronutrients (minerals and vitamins), (iii) health-promoting NGC, and (iv) fibre.

The food-based dietary guidelines to ensure fat quality for prevention of CHD in Indians provide, in addition to adequate absolute levels of individual fatty acids (and their optimal balance), high levels of natural plant sterols and other health-promoting NGC.[60,66,68]

## NEED FOR RESEARCH

Future research should focus on the natural content of plant sterols and other NGC in diets and their impact on health and disease. Studies are needed to generate a database on the content and composition of plant sterols, and other NGC in Indian foods, and the effect of traditional and industrial edible oil and food processing. Research should focus on the physiological effects of different plant sterols, synergism with other NGC of food fats in disease-preventing/health-promoting effects. Studies on the long term effects of foods enriched with plant sterols as well as the effects of plant sterols from natural (unsupplemented) foods on the metabolic syndrome and other risk factors for diet-related chronic disease need to be pursued. Manufacturing processes need to emphasize the retention of plant sterols and other health-promoting NGC in foods and vegetable oils. Since several foods enriched with plant sterols as well as those with other health-promoting substances would be sold, post-marketing surveillance may be needed to evaluate the interaction of nutrient/health-promoting substances on human health.

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