Phytosterol and its esters as novel food ingredients: A review

Rekha Chawla*, Sivakumar S and Nitika Goel

College of Dairy Science and Technology,
Guru Angad Dev Veterinary and Animal Sciences University, Ludhiana- 141 004, India.
Received: 21-05-2015 Accepted: 16-05-2016 DOI: 10.18805/ajdfr.v3i1.3576

ABSTRACT

Phytosterols or stanols are large group of compounds found exclusively in plants. These are naturally present in plants and are structurally similar to cholesterol. A daily intake of 3 g of phytosterol (or their reduced form stanols) is associated with consistent and reproducible reduction in LDL cholesterol concentrations upto 10% and reduces the risk of coronary heart disease by 20% over a lifetime. Studies have concluded that the effective doses for reduction of cholesterol are between 1.5 and 3g/day, leading to decrease in 8% and 15% of LDL-cholesterol. The principal mechanism of action is based on interference with the solubilization of the cholesterol in the intestinal mucosa. Several studies have validated the cholesterol lowering effect of phytosterols and stanols along with its role in prevention of coronary heart diseases. Plant sterols and stanols appear to be un hazardous to health in a large number of human studies and no evidence of toxicity even at high dose levels has been reported. Changing lifestyle, constant stress and risk towards various diseases have necessitated the need of such vital nutraceuticals to be incorporated in diet and daily food items. Such new foods and formulations should pave the way for greater use of phytosterols in heart health promotion, increasing the long term potential for the creation of innovative functional foods containing plant sterols and their derivatives.

Key words: Coronary heart diseases, Functional foods, LDL cholesterol, Mechanism of action, Phytosterol, Stanols.

INTRODUCTION

The term phytosterols is generally used to describe plant sterols and plant stanols collectively. Phytosterols are natural components of plant origin forming cell membrane and occur in small quantities in many fruits, vegetables, nuts, seeds, cereals, legumes, vegetable oils and other plants. Plant stanols occur in even smaller quantities in many of the same sources. Chemically, phytostanols are similar to the phytosterols, with the exception of having no double bond in their chemical structure and have a role in plants similar to that of cholesterol in mammals, e.g. forming cell membrane structures. Thus, plant stanols are hydrogenation products of the respective plant sterols, e.g. campestanol/campesterol and sitostanol/sitosterol. Consequently, the normal dietary intake of plant stanols is much less than that of plant sterols. Like plant sterols, stanols reduce levels of total and low density lipoprotein cholesterol in blood by inhibiting absorption of cholesterol in the intestine. It is estimated that 2500 tonnes of vegetable oil needs to be refined to produce 1 tonne of plant sterols (IFST. 2005). All sterols are waxy colorless solids, soluble in most organic solvents and insoluble in water (Anon 2011a).

Many researches have been undertaken in India as well as abroad, considering the health benefits of phytosterols and are discussed in detail in later heads.

Structure of phytosterols: Chemically, the phytosterols are classified as 4-desmethylsterols of the cholestanole series. Structurally, plant sterols fall into one of three categories: 4-desmethylsters (no methyl groups); 4-monomethylsters (one methyl group) and 4, 4-dimethylsters (two methyl groups). However, most of the major phytosterols such as β-sitosterol, campesterol, stigmasterol, avenasterols and plant stanols belong to the group of 4-desmethylsters (Christie et al., 2011; Wasowicz et al., 2002). Phytosterols differs very slightly in structure from the cholesterol by the presence of an ethyl or methyl group at C-24 position in the side chain (Scheme 1). There are over 40 phytosterols known today, but β-sitosterol is the most abundant one, comprising about 50 per cent of dietary phytosterols (Anon 2012a). The next most abundant phytosterol is campesterol (about 33%) and stigmastanol (about 2 to 5%). Other phytosterols found

*Corresponding author’s e-mail: mails4rekha@gmail.com.
in the diet include brassicasterol, α-7-stigmasterol and α-7-avenasterol. Structurally, β-sitosterol differs from cholesterol by the presence of an ethyl group at the 24th carbon position of the side chain, whereas in the case of campesterol, a methyl group occupies the same position. The fully saturated form of phytosterols (containing no double bond at the 5,6 position) are the phytostanols, which are present in only trace amounts but can be formed by hydrogenation of phytosterols.

**Physical and chemical properties:** In edible oils phytosterols are mainly present in free and esterified forms (Phillips et al., 2002) and form crystalline network bearing similar properties as those of conventional triglycerides and possess polymorphic behavior similar to conventional crystallizing fats. Free sterols/stanols are insoluble in water and have improved solubility in fat phase of foods. Crystalline free sterols and stanols have high melting point (142°C) and are sticky powders. Contrast to this, esterified sterols/stanols have lower M. Pt (25-43°C). Stability and solubility of phytosterols can be improved by adding emulsifiers.

Similar to cholesterol, phytosterols are prone to oxidation and undergo auto-oxidation to form oxy sterols and sterol oxides (Soupas et al., 2005). Basic property of esterified sterols depends on the fatty acid molecules attached to it (Anon, 2010). Such as esterification with unsaturated fatty acid results in lowering of melting point as compared to esterification with saturated fatty acids which renders the product with high melting solids.

**Sources of Phytosterols and its intake:** Phytosterol is abundantly present in the fat soluble fractions of all plants and foods containing plant based raw materials including principally oils, cereals, pulses and dried fruits (Piironen et al., 2000). Phytosterols may exist as free sterols (FS’s), esterified with fatty acids (SE’s) or phenolic acids (SPHE’s) or as glycosides (SG’s) and acylated glycosides (Moreau et al., 2002; Piironen and Lampi, 2003). Some packaged foods, such as specially formulated orange juices, low fat yogurts and milks are available in the market being fortified with phytosterol. Major sources of phytosterols for fortification in current foods and for the preparation of dietary supplements include tall oil and vegetable oil deodorizer distillate (Table 1). Tall oil is a by-product of kraft pulping process of wood to make paper whereas the deodorizer distillate fraction is obtained from vegetable oil refining. Process for the production of phytosterols and tocopherols from deodorizer distillates was developed by Eastman and patented in 1995 (Sumner et al., 1995).

Vegetable oils are richest source of free phytosterols and their fatty acid esters. These, in crude forms, contain 1-5 g/kg of phytosterols (Weihrauch and Gardner, 1978; Johansson et al., 1979; Piironen et al., 2000; Gunstone et al., 2005). However, fewer oils such as corn oil (7.8-11.1 g/kg) and rapeseed oil (6.8-8.8 g/kg) are exceptions of this category. Tall oil contains a higher proportion of plant stanols than do vegetable oils (IFST 2005). The amount of available phytosterols in different vegetable oils is shown in Table 2.
Refining of oils leads to significant lowering of phytosterol content (Ferrari et al., 1997) (Table 3) and therefore, it is very essential to develop industrial methods to minimize these losses (Quilez et al., 2003).

The most important sterol present in vegetable oils is β-sitosterol, a desmethyl sterol, which accounts for 38 to 95% of the total phytosterols available in various oils (Verleyen et al., 2002) whereas mono and di-methyl sterols are found in lower amount in these oils (Johansson et al., 1979; Chryssafidis et al., 1992; Eldin and Appelqvist, 1994) but certain oils such as olive and linseed oil contain substantial amounts of dimethyl sterols (Johansson 1979). Distribution of phytosterols to free sterols and steryl fatty acid esters account for different proportion in different oils (Johansson et al., 1979; Ferrari et al., 1996; Verleyen et al., 2002; Phillips et al., 2002; Worthington and Hitchcock, 1984; Gordon and Griffith, 1992) for example- free sterols accounts for nearly 54-85% of total phytosterols in soybean, sesame, olive, cotton seed, coconut, safflower, and peanut oil whereas the proportion varies for 32-44% in canola, rapeseed, corn, avocado and sunflower oil (Phillips et al., 2002).

Cereals such as rye, barley, wheat and oats are generally considered good source of phytosterol wherein germ and bran fractions are known as the best reservoirs among other fractions. The total phytosterol content of

### Table 1: Current and future sources of phytosterols for functional foods

<table>
<thead>
<tr>
<th>Source</th>
<th>Concentration of phytosterols (Wt %)</th>
<th>Types of phytosterols</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tall oil</td>
<td>10-20</td>
<td>Free phytosterols (Sitosterol) Free phytostanols (Sitostanol)</td>
<td>Robinson et al. (2000)</td>
</tr>
<tr>
<td>Deodorizer distillate from soybean oil and from other vegetable oils (palm, rape, peanut, etc.)</td>
<td>15-30</td>
<td>Free phytosterols (Sitosterol)</td>
<td>Sumner et al. (1995)</td>
</tr>
<tr>
<td>Corn fiber oil</td>
<td>10-15</td>
<td>Free phytosterols (Sitosterol) Phytostanyl fatty acyl ester Phytosteryl fatty acyl ester</td>
<td>Hicks and Moreu (2001)</td>
</tr>
<tr>
<td>Rice bran oil</td>
<td>1-2</td>
<td>Phytostanyl ferulate ester Free phytosterols (Sitosterol) Phytosteryl ferulate ester</td>
<td>Hoffpauer and Wright (2002)</td>
</tr>
</tbody>
</table>

### Table 2: Phytosterol content in various vegetable oils

<table>
<thead>
<tr>
<th>Source</th>
<th>Amount present (g/kg)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude vegetable oil</td>
<td>1-5</td>
<td>Wehrauch and Gardner, 1978; Piironen et al., 2000.</td>
</tr>
<tr>
<td>Corn oil and rapeseed oil</td>
<td>8-22 and 5-11</td>
<td>Gunstone, 2005</td>
</tr>
<tr>
<td>Wheat germ and corn germ oil</td>
<td>17-26 and 10.7</td>
<td>Homberg and Bielefeld, 1989</td>
</tr>
<tr>
<td>Palm oil and coconut oil</td>
<td>0.7-0.8 and 0.7</td>
<td>Verleyen et al. 2002</td>
</tr>
<tr>
<td>Crude soybean oil</td>
<td>3-4.4</td>
<td>Moreau et al., 2002</td>
</tr>
</tbody>
</table>

### Table 3: Change in phytosterol content after refining process in vegetable oils (g/kg)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Sitosterol</th>
<th>Stigmasterol</th>
<th>Campesterol</th>
<th>Brassicasterol</th>
<th>Avenasterol</th>
<th>Stanols</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn (C)</td>
<td>5.41-6.46</td>
<td>0.58-0.68</td>
<td>1.69-2.01</td>
<td>—</td>
<td>0.10-0.11</td>
<td>—</td>
<td>7.80-11.14</td>
</tr>
<tr>
<td>Corn (R)</td>
<td>4.54-5.43</td>
<td>0.46-0.59</td>
<td>1.23-1.64</td>
<td>ND</td>
<td>0.10-0.41</td>
<td>0.23-0.33</td>
<td>6.86-7.73</td>
</tr>
<tr>
<td>Olive (EV)</td>
<td>1.18-1.33</td>
<td>0.009-0.013</td>
<td>0.045-0.05</td>
<td>ND</td>
<td>0.17-0.22</td>
<td>0.003-0.007</td>
<td>1.44-1.62</td>
</tr>
<tr>
<td>Olive (CP)</td>
<td>1.22-1.30</td>
<td>ND-0.03</td>
<td>0.02-0.05</td>
<td>ND</td>
<td>0.16-0.60</td>
<td>0.03-0.04</td>
<td>1.56-1.93</td>
</tr>
<tr>
<td>Palm (C)</td>
<td>0.43-0.52</td>
<td>0.07-0.10</td>
<td>0.14-0.20</td>
<td>ND</td>
<td>ND-0.03</td>
<td>—</td>
<td>0.69-0.79</td>
</tr>
<tr>
<td>Palm (R)</td>
<td>0.35-0.41</td>
<td>0.07-0.10</td>
<td>0.14-0.18</td>
<td>ND</td>
<td>ND-0.03</td>
<td>ND-Tr</td>
<td>0.60-0.68</td>
</tr>
<tr>
<td>Peanut (R)</td>
<td>1.15-1.69</td>
<td>0.12-0.22</td>
<td>0.224-0.38</td>
<td>0.01</td>
<td>ND-0.03</td>
<td>0.03</td>
<td>1.67-2.29</td>
</tr>
<tr>
<td>Rapeseed (C)</td>
<td>4.20</td>
<td>ND</td>
<td>2.93</td>
<td>1.11</td>
<td>—</td>
<td>—</td>
<td>6.82-8.78</td>
</tr>
<tr>
<td>Rapeseed (R)</td>
<td>3.58-3.95</td>
<td>ND-0.16</td>
<td>1.64-3.00</td>
<td>0.51-0.92</td>
<td>0.14-0.36</td>
<td>0.02-0.12</td>
<td>6.39-7.67</td>
</tr>
<tr>
<td>Soybean (C)</td>
<td>1.73-1.83</td>
<td>0.58-0.61</td>
<td>0.57—0.71</td>
<td>—</td>
<td>0.11-0.14</td>
<td>—</td>
<td>3.04-4.44</td>
</tr>
<tr>
<td>Soybean (R)</td>
<td>1.24-1.73</td>
<td>0.37-0.64</td>
<td>0.34-0.82</td>
<td>ND-0.007</td>
<td>0.04-0.14</td>
<td>ND-0.07</td>
<td>2.03-3.28</td>
</tr>
<tr>
<td>Sunflower (R)</td>
<td>1.94-2.57</td>
<td>0.18-0.32</td>
<td>0.27-0.55</td>
<td>0.02</td>
<td>0.19-0.56</td>
<td>0.04</td>
<td>2.63-3.76</td>
</tr>
</tbody>
</table>

(Source: Piironen and Lampi, 2003)
ND: Not Detected; Tr= Traces, — Not reported
Where C stands for crude; R =refined; EV= extra virgin; and CP cold pressed
various cereals varies from about 350-1200 mg/Kg (on wet basis). In cereals, sitosterol dominates among all phytosterols and its proportion ranges from 49-64% in wheat, rye, barley and oats Piironen et al., 2003. Stanols are present abundantly in rye, wheat and corn; and has been reported @ 23 and 26 % in rye and wheat, respectively (Dutta and Appelqvist, 1996). Table 4 shows the composition of major phytosterol in different cereal grains.

Vegetables, fruits and berries are not as good source of plant sterols as vegetable oils and cereals, on a fresh weight basis. However, the variation in their sterol content is remarkable when the results are calculated on dry weight basis. Piironen et al., 2000 have analyzed various vegetables for total sterols and reported a range of 5-37mg/100 g (on fresh weight) and 25-410 mg/100g (on dry weight) available in them. Results revealed cabbage and cauliflower as good source while potato as poor source of phytosterols, whereas fruits and berries were found to contain even lower amount of phytosterols than vegetables.

Absorption of Phytosterols: Initially, it was demonstrated that phytosterols are unabsorbable in rodents and rabbits. However, Salen et al., 1989 estimated 1.5-5% absorption of sitosterol in human beings. Ostlund (2002) reported about 0.5% of sitosterol and 1.89% of campesterol absorption in human beings which reduced by 91% when the saturated form i.e. stanols was used. With the development of newer analytical techniques, various animal species showed phytosterols’ absorption ranging from 0-4% in rabbit & rats and 6% in human beings (Pollak and Kritchevsky, 1981). Data also showed that some phytosterols get metabolized into acidic products (Kritchevsky and Chen, 2005).

Mechanism of action and health benefits: The initial studies demonstrating the cholesterol lowering effect of phytosterols in humans were reported by Pollak (1953) in the early 1950’s and till date research is continuing to study various aspects of phytosterols on human health. Plant sterols especially β-sitosterol which is most widely present in foods might protect against certain type of cancer such as colon, breast and prostate (Rao and Koratkar, 1997; Awad and Fink, 2000a). Phytosterols are also known to have several bioactive properties with possible implications for human health (Cherif et al., 2010). However, the primary focus of recent scientific literature has been on the cholesterol lowering effect of phytosterol & stanol esters and their health implications. The exact mechanism by which phytosterols decrease serum cholesterol levels is not yet completely understood but several theories which have been proposed and are as follows:

• Rozner and Garti (2006) suggested that in the intestine, marginally soluble cholesterol is precipitated into a non-absorbable state in the presence of added phytosterols and stanols.

• Phytosterols may reduce cholesterol absorption by competing with cholesterol for incorporation into the bile salt micelles or for uptaking of cholesterol by enteroocytes through Niemann Pick C1 Like 1 (NPC1L1) transporter. In addition, phytosterols may enhance cholesterol excretion back into the intestinal lumen through the adenosine triphosphate binding cassette G5 (ABCG5) and G8 (ABCG8) transporters. Phytosterols could also prevent esterification of the free cholesterol into cholesterol esters and thus it’s assembling into the chylomicrons (Jones and AbuMweis, 2009).

Unlike cholesterol, phytosterols and phytostanols are poorly absorbed and the small absorbed amount is actively re-excreted in the bile. This results in low serum levels of these sterol molecules. The inhibition of cholesterol absorption is thought to produce a state of relative cholesterol deficiency that is followed by upregulation of cholesterol biosynthesis and LDL receptor activity (Ling and Jones, 1995). Some unsaturated vegetable oils increase hepatic LDL receptor activity, decreasing LDL production and increasing LDL clearance. This action corresponds to what is anticipated from the known effect of phytosterols to reduce delivery of dietary and biliary cholesterol to the liver.

Cholesterol lowering effect of phytosterols and coronary heart diseases: The cholesterol-lowering effect of phytosterol/stanol enriched foods has been well documented (Law 2000 and Plat et al., 2000). Systematic reviews studying the efficacy of phytosterols have shown that phytosterol/

<table>
<thead>
<tr>
<th>Sample</th>
<th>Campesterol</th>
<th>Sitosterol</th>
<th>Stigmasterol</th>
<th>Avenasterol</th>
<th>Stanols</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barley</td>
<td>150-192</td>
<td>437-484</td>
<td>24-36</td>
<td>56-69</td>
<td>17-19</td>
<td>720-801</td>
</tr>
<tr>
<td>Buck wheat</td>
<td>93</td>
<td>775</td>
<td>Tr</td>
<td>40</td>
<td>23</td>
<td>963</td>
</tr>
<tr>
<td>Corn</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>662-1205</td>
</tr>
<tr>
<td>Millet</td>
<td>112</td>
<td>371</td>
<td>18</td>
<td>87</td>
<td>ND</td>
<td>770</td>
</tr>
<tr>
<td>Oats</td>
<td>32-46</td>
<td>237-321</td>
<td>11-21</td>
<td>15-56</td>
<td>8-9</td>
<td>350-491</td>
</tr>
<tr>
<td>Rice</td>
<td>146</td>
<td>375</td>
<td>104</td>
<td>20</td>
<td>32</td>
<td>723</td>
</tr>
<tr>
<td>Rye</td>
<td>128-210</td>
<td>358-607</td>
<td>22-37</td>
<td>5-42</td>
<td>122-220</td>
<td>707-1134</td>
</tr>
</tbody>
</table>

(Source: Piironen and Lampi, 2003)
ND: Not Detected; Tr= Traces, — Not reported
Phytosterols compete with cholesterol absorption and uptake in the small intestine thereby reducing the supply of cholesterol in the blood stream. Since high blood total cholesterol and low-density lipoprotein (LDL) cholesterol levels are the main risk factors for coronary heart disease (CHD) and other diseases related to atherosclerosis, thus reducing cholesterol levels reduces the risk of CHD as well. According to recent data, cardiovascular disease (CVD) is a leading cause of death and a major cause of disability in Australia. One recent data reports that nearly 47,000 Australians died from CVD in 2007 (Australian Bureau of Statistics, 2009) and in India according to a report generated by India Today; CVD is at the top position among the top ten causes of deaths in India with a percentage of 24.8 (Anon 2012b). In this context phytosterols have no effect on the levels of triacylglycerol or HDL cholesterol. Studies showed daily intake of 2-3 g sterols and stanols lowers LDL level by 10% and likely lowers CHD by 12-20% in the first 5 years and by 20% over a life time (Weststrate, and Meijer, 1998). Phytosterols are absorbed from the blood into the body at a rate of 5-10%, whereas cholesterol is absorbed at a rate of 50% (Awad et al., 2000b). Another study was carried out in a group of variable children with familial hypercholesterolemia (FH) aged 7-12 years where children were given phytosterol esters 18.2 +/- 1.5 g in spreads per day, corresponding to 1.60 +/- 0.13 g daily intake of phytosterol esters during the study period (Amundsen et al., 2001 and 2002). This effect was maintained during a further six-month open label follow up period. The spreads were well tolerated by the children with no adverse effects reported. The study confirmed potential benefit of their use by children with familial hypercholesterolemia.

Phytosterols have also been used in various enriched food products, these authors found that the optimal daily dosage of sterols or stanols is 2g/day can result in a 10% reduction in LDL cholesterol, whereas higher doses provide only a small additional effect.

It was observed that phytosterol esters are hydrolyzed by pancreatic cholesterol esterases (SCF, 2000). Thus, act similar to free phytosterols in their ability to lower cholesterol absorption in rats, suggesting that the liberated phytosterols are the active moieties of the esters (Mattson et al., 1997). Recent animal studies have suggested that phytosterols reduce atherosclerosis in the Apo-E deficient mouse model whereas the evidence from human studies is mixed and does not approve or disprove an increase in atherosclerotic risk from serum phytosterol levels (John et al., 2007). Schonheimer (1931) also showed that sitosterol, stigmasterol, ergosterol and brassicasterol are not absorbed by rodents or rabbits.

In an efficacy study on plant stanols, a daily consumption of 24 g of spread, containing 2-3 g of plant stanol esters resulted in lowering of total serum cholesterol and LDL cholesterol by 6.4 per cent and 10.1 per cent respectively (Nguyen et al., 1999; St-Onge et al., 2003). A dose dependent decrease in total and LDL cholesterol was observed with increasing levels of plant stanol esters up to a level of 1.6 g per day. However, increasing the dose from 2.4 g to 3.2 g did not provide any clinically important additional effect (Hallikainen et al., 2000a; 2000b). These have also appeared to be equally effective in lowering plasma total and LDL cholesterol (Weststrate and Meijer, 1998; Law, 2000). Dairy products being high in cholesterol are often regarded as the one to be used with agents that can lower the cholesterol levels. Considering the fact of sesame rich in phytosterol, various concentrations of sesame oil was incorporated in shrikhand and further analysis was carried out to check maximum retention and nutritive value of the
product. Results indicated that 8% of sesame seed oil incorporated shrikhand sample shown high nutritional value, antioxidant property and presence of phytosterol compared with control sample (Abilasha et al., 2016).

To examine the effect of a food enriched with phytosterols on blood levels of cholesterol and nutrients, researchers randomly assigned 67 people with high cholesterol to eat two snack bars containing 1.5 grams of phytosterols each day for six weeks or two bars that did not contain phytosterol. The subjects who had enriched bar showed 5 percent reduction in total cholesterol and 6 percent reduction in LDL cholesterol after six weeks. Also, an increase in the amount of HDL or “good” cholesterol in relation to total cholesterol was observed. However, the phytosterol enriched bars did not affect vitamins A or E levels in blood but at the same time reduction in β-carotene levels had been reported (Anon 2006). Similar observations were recorded by Katan et al (2003) and Hallikainen and Uusitupa (1999).

Also, the effect of phytosterols on physical and rheological properties of yogurt was assessed and the results indicated that in enriched yogurt, apparent viscosity and syneresis were lower and firmness was higher compared to the control. However, addition of phytosterol to the yogurt had significant effect on acidity (Izadi et al., 2015).

Phytosterols and cancer: As plant components, phytosterols (PS) may offer protection against cancer by several different means (Rao and Koratkar, 1997; Awad and Fink, 2000). These include inhibiting cell division, stimulating tumor cell death and modifying some of the hormones that are essential to tumor growth (Awad et al., 2000b). Long-term studies showed an association between the amount of plant sterol consumed in the diet and developing cancer. For example, the incidence of colon, prostate, and breast cancers in Western countries are at much higher rate compared to Asian countries, where the consumption of phytosterols is more by 3-4 times. It is estimated that about 9 million new cancer cases are diagnosed every year and over 4.5 million people die from cancer each year in the world (Reddy, 2012). However, the estimated number of new cancers in India per year is about 7 lakhs and over 3.5 lakhs people die of cancer each year. Also, 2005 data shows that India has one of the highest cancer rates in the world (Anon, 2006). Out of these 7 lakhs new cancers about 2.3 lakhs (33%) cancers are tobacco related. The Western diet contains approximately 80 mg PS/day, whereas Asian vegetarian diets contain 345 mg PS/day and Japanese diets contain 400 mg PS/day (Anon, 2000).

Phytosterols have been found useful in treating other conditions, including rheumatoid arthritis, but their widest application is in protecting the heart. However, reports also suggest that excessive intake of dietary phytosterols and stanols in plasma and tissues may contribute to the increased blood pressure (Chen et al., 2010).

Safety of phytosterols: Based upon results of clinical studies, plant sterols appear to be safe (Katan et al., 2003; Hendriks et al., 2003; Hepburn et al., 1999) and non-toxic (Christiansen et al., 2001; Hendriks et al., 1999) and no adverse effect has been found on the reproductive system (Baker et al., 1999; Waalkens et al., 1999). The U.S. Food and Drug Administration (FDA) granted GRAS “Generally Recognized as Safe” status for plant sterols/stanols, and the European Union Scientific Committee on Foods has concluded margarines and dairy products containing phytosterol esters are safe for human consumption. The FDA has also approved a health claim that foods containing plant sterols/stanols esters may reduce the risk of coronary heart disease (European Food Safety Agency, 2003) by reducing blood cholesterol levels as part of a diet low in saturated fat and cholesterol. However, the only drawback with phytosterols is that these require fat based medium to get solubilize and the problem can be overcome by emulsification with lecithin and delivering in non-fat or low-fat foods and beverages. This can reduce the amount of fat in fat-based preparations substantially with retention of bioactivity and reduction in cholesterol (Ostlund, 2004). Table 5 depicts the potential uses of phytosterol along with its future applications in non-fat dairy products.

Phytosterols in products: Due to increasing consumer knowledge in functionality and health benefits, market of phytosterols containing products is growing continuously and various ready to eat products are available in market containing the phytosterols and stanols as novel ingredients as in yellow fat spreads (Wolfs et al., 2006). Also, their effectiveness in lowering both total and LDL-cholesterol in human subjects when incorporated to other foods matrices

Table 5: Phytosterol: applications and opportunities

<table>
<thead>
<tr>
<th>Current uses</th>
<th>Potential uses</th>
<th>Novel forms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Margarines, fat spreads, soft spreadable</td>
<td>Baked pastry products, egg noodles and pasta, custard, ice cream, frozen</td>
<td>Encapsulation with egg proteins to increase</td>
</tr>
<tr>
<td>cheeses, mayonnaise, salad dressings,</td>
<td>desserts, muesli bars and soups, meat products, rice beverages, cereal        bioavailability in foods</td>
<td></td>
</tr>
<tr>
<td>low fat dairy products, milk, yogurt</td>
<td>grains and flours, food flavourings etc.</td>
<td>Water soluble powders for inclusion in beverages</td>
</tr>
<tr>
<td>and cheeses, snack and energy bars,</td>
<td></td>
<td>(orange juice) and non fat foods.</td>
</tr>
<tr>
<td>frying oils, breakfast cereals etc.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Source: Anon, 2008)
(yoghurt, milk, salad dressing and lean ground beef) has also been successfully demonstrated and indicated no side effects (Volpe et al., 2001; Davidson et al., 2001; Judd et al., 2002; Carr et al., 2001; Matvienko et al., 2002; John et al., 2007, Polagruzo et al., 2006; Miettinen et al., 1995; Hendriks et al., 1999 and Hallikainen et al., 2000a). These results have led to the market introduction of several foods enriched or fortified with phytosterols. Since fats are necessary to solublize sterols, hence foods with majority of the fat phase eg. Butter or margarines are an ideal vehicle for them, although cream cheese, salad dressing, and yogurt can also be used. Phytosterols can also be incorporated into variety of food stuffs of bakery origin and fruit juice, ice cream and other vehicles (Clifton, 2002). Commercially, phytosterols are currently contained in bars (Australia, England), vegetable oils (Japan, Israel), orange juice, mayonnaises (Australia), milk (England, Australia, and Argentina), yoghurt (Australia, England), yoghurt drinks, soy milk, meat and soups (Finland), and green teas (Korea) (Berger et al., 2004).

Since novel foods approval in the year 2000, Unilever launched yellow fat spreads containing phytosterol esters in 12 EU countries. The recommended intake is 2-3 servings per day from the range of foods containing phytosterol esters which is equivalent to a daily intake of 2-3g free phytosterol. The currently available phytosterol fortified products in the market include: yellow fat spreads (fat content from 32-63%), yoghurt (natural, vanilla, toffee and various fruit flavoured), semi-skimmed milk, chicken balls, chicken gratin (chicken dish with potatoes and cream), sausages, salads (potato and beet root), mayonnaise, cereal bars (chocolate chip, raisin nut and apricot), and soft cream cheeses (natural, garlic and herbs) and various brands with their brief specification is as follows:

- Promise active® Light Spread – formerly Take Control, each tablespoon contains one gram of plant sterols and 45 calories
- Minute Maid® Premium Heart Wise® juice – an eight ounce serving contains one gram of plant sterols
- Right Direction Chocolate Chip Cookies™ – one cookie contains 1.3 grams of plant sterols
- Silk® Heart Health – one cup of soy milk contains 0.65 grams of phytosterols
- Krusteaz® healthy start frozen breakfasts – a CoroWise™ brand; one serving of pancakes is 0.65 grams of plant sterol esters.

CONCLUSION

The availability of phytosterol containing products is gradually becoming more widespread due to awaken awareness and education of mass. Also, regulatory hurdles governing their use in foods are steadily overcoming. However, the only dark side effect of such products is with the interference with the absorption of carotenoids, which can be compensated by adding these compounds in appropriate carriers. Phytosterols also has anti-cancerous properties and act as immune system modulators. There are several possible future lines of research, as finding raw materials containing phytosterol content in abundance, minimization of losses during recovery processes and addition of purest form in ready bio-available product in the market and its easy availability. These ingredients should be incorporated in diet in sufficient amounts to reap the potential benefits of phytosterols. At the same time, the genetic bases of their action must be elucidated, synergic effects with other compounds must be studied along with its minimal side effects and the effects of long-term treatment must be defined precisely.

REFERENCES


