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Review article

# Health interest of cholesterol and phytosterols and their contribution to one health approach: Review

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ABSTRACT

Plants and animals are potential sources of food, particularly lipids. They are sources of nutrients for humans, and are used in various applications in food industries. Foods whose lipids consumed, have benefits for animal and human health. Sterols are among the compounds essential to the well-being of living beings. Phytosterols are derived from plants and algae, and zoosterols from animals dominated by cholesterol. Cholesterol is found in small quantities in some plant lipids. Also, cholesterol is produced by herbivorous insects by metabolizing phytosterols. Oilseeds and vegetable oils contain sterols and are the richest natural sources of phytosterols. Vegetables and fruit also contain small quantities. These compounds play an undeniable role in our diet. Foods, particularly vegetable oils, when produced, preserved and used according to established prescriptions, help to ensure consumer health and prevent certain pathologies. Sterols, and in particular phytosterols, play a number of roles in the pharmaceutical field (therapeutic steroids), nutrition (anti-cholesterol, anti-cancer properties). These natural molecules with their nutritional and therapeutic properties have a positive impact on human and animal health, and possibly on vegetative growth (development cycle of plants). The same is true for cholesterol, which has multiple functions in humans and animals. Also, a diet based on plants or their by-products with positive effects on human and animal health is closely in line with the objectives of the 'One health approach'. Indeed, sterols can have adverse effects on health when established standards are not respected. As a result, the health benefits of sterols (cholesterol and phytosterols) require particular attention, given their contribution to the public health problems facing our countries. The aim of the present research is to highlight the health benefits of cholesterol and phytosterols for living organisms, particularly humans, and their contribution to the One Health approach.

## 1. Introduction

Foodstuffs are sources of nutrients for human well-being [1]. They are made up of microelements and macroelements [2], which include oils and fats of both plant and animal origin. Indeed, plant, fungal and animal cells content diversity compounds, such as sterols. Plants synthesize a complex mixture of sterols called phytosterols. Fungal and mammalian cells contain zoosterol's with one

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major sterol, the cholesterol. However, cholesterol can also be found in some plants [3]. Sterols are unsaponifiable constituents naturally present particularly in the fat or oil [4]. These compounds are abundant and responsible for some of the important properties of oils or fats [5]. Oils have many properties and applications of their own and content varying according to factors such as season, geography, temperature and genetics [6]. Edible oils of vegetable origin are obtained from oilseeds such as soya, rapeseed, sunflower, argan, peanut and many others, or from oleaginous fruits such as copra, olive and palm oil, obtained respectively from coconut, olive and oil palm [7]. As a result, they represent a vast and varied group of fats of different origin, composition, quality and taste [5]. Among the compounds found in vegetable oils, sterols have been confirmed by several authors [8–10]. Sterols, more specifically phytosterols, have been identified in edible oils, in particular β-sitosterol, campesterol and stigmasterol. As with plant products, animal products are rich in cholesterol and other sterols [11]. Sterols are essential to almost all eukaryotes and their distribution differs in plants and animals [12]. Phytosterols play a number of roles in pharmaceuticals and nutrition [13], such as anti-diabetic, anti-inflammatory and cholesterol-lowering properties, among others [14]. Cholesterol is an essential compound for the human organism, but its excess can be the cause of several diseases, including cardiovascular disease [15]. In addition to their important role in the development cycle of plants in their environment, sterols are indispensable for animals and humans when the conditions of use comply with the nutritional and therapeutic provisions laid down. In fact, studies have shown that plant compounds such as green tea consumption have positive effects on cholesterol reduction in both humans and animals [16–18]. Herbivorous insects and algae also contain sterols [19,20]. For example, seaweed sterols are effective therapeutic alternatives [21]. Thus, sterols have a contributory role to play in the One Health approach. One Health is widely defined and generally refers to the interconnectivity between environmental, animal and human health [22]. More specifically, One Health is the concept that the health of humans, animals, and the environment are inextricably linked. Therefore, sterols have an important role in animal, human and environmental health. Stakeholders including consumers and researchers play an important role in influencing food safety policies and sustainable food production practices [23]. So, knowledge of this interaction is important for action against public health problems. This study focuses on oilseeds, particularly vegetable oils, in view of the abundance of sterols in vegetable oils.

## 2. Sources of phytosterols and cholesterol

### 2.1. *Sources of phytosterols*

Plant sterols biosynthesis of takes place mainly in the endoplasmic reticulum, starting with acetyl-CoA, which is then converted to squalene via the mevalonate (MVA) pathway involving an important enzyme, 3-hydroxy-3 methylglutaryl-CoA (HMG-CoA) reductase, leading to cycloartenol. Sterols such as campesterol, β-sitosterol and stigmasterol are obtained from cycloartenol by a battery of enzymes, SMT (C24-sterol methyltransferase) and CYP710A [24]. Plant sterols or phytosterols are found in plants, particularly in oilseeds. As a result, edible oils are their main source of phytosterols [25]. There are over 250 plant sterols, differing in function and availability [26]. The main phytosterols are β-sitosterol, campesterol and stigmasterol [27]. β-sitosterol, campesterol and stigmasterol constitutes 65 %, 30 %, and 3 % of total dietary sterol intakes from herbal nutrition, respectively [28]. Apart from vegetable oils, which are the richest natural sources of phytosterols, sterols are present in nuts, cereal products, vegetables, fruit and berries [29]. In general, they are present in small quantities in vegetables and fruit. Sesame seeds and wheat germ are among the richest in phytosterols, while corn and rapeseed oils contain sufficient [30]. Human organism is unable to synthesize phytosterols, and must be obtained from the diet [31]. Phytosterols such β-sitosterol, stigmasterol, and campesterol have also been found in cow, goat, buffalo, and camel milk fat [32]. They are steroidal alcohols, with chemical structures similar to cholesterol [33]. Phytosterol structures differs from that of cholesterol by their side chains [34]. Sterols can be converted by enzymatic hydrogenation in plants or during food processing into plant stanols [35]. Physiologically, phytosterols or their phytostanols derivatives are virtually not absorbed by the body, as they compete with cholesterol in the digestive tract [36]. Hydrogenation of phytosterols produces compounds known as phytostanols. Plant stanols such as cholestanol, campestanol, and sitostanol are main stanol derivatives of plant sterols [37]. Phytostanols are present in foods of plant origin [34] and are abundant in cereals, particularly wheat and rye [38]. Sitostanol and campestanol are the most abundant phytostanols in the human diet [34]. On average, phytosterols fraction represents 0.1–0.5 % [39], or 100–500 mg/100g of oil [40]. High levels have been found in corn oil (914 g/100g), rapeseed oil (713 g/100g) [41] and sesame oil (506 g/100g) [42]. Also, the highest concentrations are found in unrefined vegetable oils [43]. Sterols have also been identified in algae and fungi. They have been found in algae such as *chlorophyceae*, *rhodophyceae* and *pheophycea*e [44]. Phytosterol contents ranged from 7 to 34 g per kg (0.7%–3.4 %) in four different microalgae oil extracts (*Isochrysis galbana, Nannochloropis gaditana, Nannochloropsis* sp. and *Phaeodactylum tricornutum*) [45]. Microalgae are a valuable alternative to higher plants as a source of phytosterols for human consumption. The phytosterols most frequently found in microalgae are brassicasterol, campesterol, stigmasterol, fucosterol, clionasterol, ergosterol and β-sitosterol [20].

### 2.2. *Sources of cholesterol*

Sterols of animal origin are called zoosterols, of which the main one is cholesterol, essentially provided by a meat diet such as meat, dairy products and eggs [46]. Cholesterol is a lipid substance [47] classified as an alcohol, of which around two-thirds of absorbed cholesterol is of biliary origin and one-third comes from the diet [48]. Two-thirds of cholesterol is biosynthesized in the cytoplasm of liver and intestine cells through the activity of HMG-CoA. The starting molecule for cholesterol synthesis is acetate, which is converted to farnesyl pyrophosphate by several enzymes, including HMG-CoA reductase. This leads to squalene through the action of squalene synthase, then to the synthesis of steroidal (cholesterol) or non-steroidal products [49]. Food cholesterol is only a minority of intestinal cholesterol [50]. The diet provides around 400 mg of cholesterol per day, and the liver produces around 1 g of cholesterol per day [51]. In order to maintain cholesterol homeostasis, all of these inputs must be used or eliminated by the body [51]. The cholesterol present in human blood and tissues comes from the diet and from the synthesis of endogenous cholesterols [52]. Foodstuffs richer in cholesterol include brains (3100 mg/100 g), egg yolk (1140 mg/100 g), butter (224 mg/100 g), cod liver oil (510 mg/100 g), shrimp (280 mg/100 g), cheese (90 mg/100 g), minced steak 20 % (84 mg/100 g), pork liver pâté (95 mg/100 g) and pâté campagne (140 mg/100 g) [50]. Cholesterol is present in microalgae. The most widespread sterol is cholesterol. It is found in one-third (34 %) of microalgae and is considered typical of red algae [20]. Cholesterol is the most common sterol in insects. Herbivorous insects produce cholesterol by metabolizing phytosterols [19].

There is a widespread belief that plants do not contain cholesterol. This misconception is the result of the fact that plants generally contain only small amounts of cholesterol, and that analytical methods for detecting cholesterol in this range were not well developed until recently [53]. The other reason is due to the legality of food labelling, which allows small amounts of cholesterol in foods to be called zero or free cholesterol [54]. Cholesterol, long considered to be exclusively animal, has now been demonstrated in many plants [55,56]. Cholesterol is found in small quantities in some plant lipids or barely present in plants [57] or oilseed plants. Examples include palm oil [58], tomato seed oil [59], camelina oil (around 200 mg/kg) [8], peanut oil [9] and cottonseed oil [10]. Authors such as Okpuzor et al. [9], Dimberu [10], Shulka et al. [8] stipulate in their work that cholesterol has been detected in vegetable oils. According to Kamm et al. [60], the biosynthetic conversion of β-sitosterol during the deodorization process yields cholesterol. Thus, cholesterol levels may be increased during deodorization as a result of steam treatment due to biosynthetic conversion [60]. Other zoosterols are found in diet. Lanosterol, lathosterol, desmosterol, dihydrolanosterol, have also been found in cow, goat, buffalo, and camel milk fat [32].

## 3. Health impacts of sterols

Phytosterols are involved in the plant's development cycle, enabling it to play its role in the environment. Plants and by-products containing phytosterols are used in human and animal nutrition, with important effects on health and nutrition. Fig. 1 summarizes the sources of sterols and their health implications for living organisms.

### 3.1. *Positive impact on animal and human health*

Phytosterols play a number of roles in various fields, such as pharmaceuticals (therapeutic steroids), nutrition (anticholesterol, prevention of cancer, cardiovascular and metabolic diseases), and cosmetics [61]. Plant sterols exist as free alcohols, fatty acid esters, steryl glycosides and acyl steryl glycosides [42,54]. In oils, phytosterols are mainly present in free and esterified forms [42]. Plant sterols have attracted the most interest for their cholesterol-lowering properties. Thanks to their amphiphilic properties, they inhibit intestinal cholesterol absorption by replacing it in bile salt micelles [62,63]. Phytosterols and dietary cholesterol are mainly absorbed in the intestine by the NPC1L1 transporter [64]. Phytosterols and phytostanols compete with cholesterol in the intestine, reducing its absorption. The absorption of phytosterols is much lower than that of cholesterol. The absorption of phytostanols and their plasma concentration are still much lower than those of phytosterols [65,66]. Tatu et al. [67] showed that sitostanol esters incorporated into

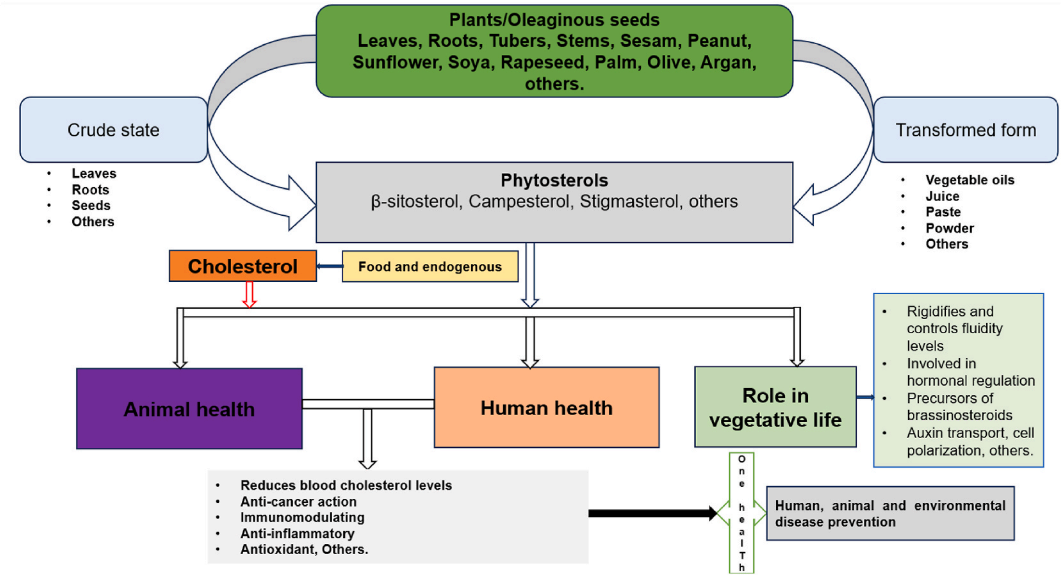

**Fig. 1.** Sterols and their contribution to the health of living beings. Sterols in food plants, whether used in their natural state or processed, are essential to animal and human health, and to the vegetative life that contributes to the One Health concept.

margarine reduced total cholesterol and low-density lipoproteins-cholesterol (LDL-C) by 10 % and 14 % respectively, in patients with moderate hypercholesterolemia (cholesterol 25.58 mmol/L). Also, it has long been demonstrated by the results of animal studies that phytostanols are more effective than phytosterols in inhibiting cholesterol absorption and reducing serum cholesterol levels [68]. Plant stanols maintained their cholesterol-lowering effects for a long time while the efficacy of sterols decreased after 1 or 2 months. Phytosterols lower LDL-C levels by reducing intestinal cholesterol absorption by 30%–50 % [69]. It has also been suggested that phytosterols inhibit cholesterol biosynthesis and that β-sitosterol in particular interferes with micellar cholesterol absorption [70]. Taking 3 g/day of phytosterols reduces intestinal cholesterol absorption by 50 %, while increasing to 9 g/day brings no further reduction. Thus, cholesterol absorption is maximally reduced with 3 g/day. The recommended dose of phytosterols for lowering blood cholesterol levels is 2 g/day [71]. In addition to their effect on reducing blood cholesterol levels, phytosterols have also been studied for their immunomodulatory actions [72]. With regard to their anti-carcinogenic effect, phytosterols have been shown to reduce the risk of lung [73], breast [74], esophagus [75], stomach [76], colon and ovarian cancers [75]. Phytosterols have antiproliferative functions, antipyretic and hormone-like effects [77]. Daily amounts to reduce the risk of colon cancer are over 122 mg [78] and over 521 mg for ovarian cancer [75]. In addition to reducing LDL cholesterol levels, daily consumption of 2 g phytosterols and/or stanols helps prevent cardiovascular disease [79]. Also, consumption of phytosterols is associated prevent to Obesity [80]. Some phytosterols also have anti-pyretic, analgesic, anthelmintic, antimutagenic properties [81] anti-inflammatory, anti-adipogenic, anti-diabetic, anti-Alzheimer and anti-atherosclerosis activities. Phytosterols have antimicrobial activity against human pathogens, in particular bacteria, fungi, viruses and protozoa [82]. At the immune level, they could stimulate immune responses following test results from HIV-infected individuals [83] and tuberculosis patients. In addition to these properties, phytosterols act chemically as antioxidants and radical scavengers, and physically as membrane stabilizers [84]. Some food products are enriched with phytosterols, notably margarines, fresh dairy products, condiment sauces, soy, fruit drinks, cereal and sausage. Over $300 million is spent worldwide each year on phytosterol-enriched functional food [85]. Consumption of phytosterol-enriched products at 1.5–2.4 g/day, lower total cholesterol and LDL-C concentration by around 10 % over periods of a few weeks to 1 or 2 years [30]. Phytosterols could reduce the activity of enzymes involved in testosterone metabolism in male animals and intervene in multicellular organisms including nematodes [86]. As a reminder, fungi, algae and protozoa synthesize 24 β-methyl sterols or ergosterols while plants synthesize 24 β-ethyl sterols [87].

Cholesterol has multiple functions in humans and animals in general. In addition to its role in the development of the nervous system, and in the formation of vitamin D required for calcium absorption, mineralization and bone formation [47], it is the precursor of adrenal and gonadal steroid hormones. Finally, it is involved in the formation of bile and the structure of mammalian cell membranes. Also, cholesterol plays an important role in embryonic development [88] and is a bile salt used in digestion [89]. It plays an important role in maintaining the rigidity and fluidity of cell membranes [90]. Cholesterol is crucial for lifelong growth and development. Cholesterol metabolism modulation therapy can be associated with existing clinical therapies to improve tumor treatment efficacy [91]. It is vital for sperm development, immune system defense [92]. Studies have shown that pharmacological modulation of intracellular cholesterol balance may be efficacious in controlling cancer progression. Cholesterol is a key modulator of apoptotic pathways [93]. Its endogenous synthesis is sufficient to ensure all its physiological functions. Dietary intake of cholesterol is therefore not essential [50,94], especially as synthesis capacities increase, if necessary, as is the case in vegetarians [50]. The different pathways involve each lipoprotein: the enterohepatic pathway (chylomicrons), the pathway supplying cholesterol to peripheral tissues through the very low-density lipoprotein (VLDL), intermediate density lipoprotein (IDL) and low-density lipoprotein (LDL), and the pathway transporting cholesterol back to the liver (HDL) [51]. LDL-C is responsible for cardiovascular disease, while high-density lipoprotein-cholesterol (HDL-C), which has a protective effect on the cardiovascular system, is called “good cholesterol” [95]. Indeed, HDL have anti-oxidant, anti-inflammatory, anti-thrombotic, and anti-apoptotic properties, which may also contribute to their ability to inhibit atherosclerosis [96]. In a study of diabetics and non-diabetics, it was suggested that increasing HDL cholesterol helps to eliminate excess bad cholesterol by cleansing tissues and returning cholesterol to the liver [97]. Dietary cholesterol intake is between 300 and 500 mg per day, compared with endogenous production of between 600 and 900 mg per day. Bile is the body’s main route of cholesterol excretion, mainly in the form of unesterified cholesterol. In adult humans, around 400 mg of cholesterol per day is converted into bile acids, and only around 50 mg is converted into hormones [94]. Other minor sterols detected in milk have beneficial bioactive properties for human. Lanosterols are milk sterols known to have preventive effects against colon cancer [32].

### 3.2. Negative impact on animal and human health

The European Food Safety Authority (EFSA) has set a maximum daily intake of 3 g of sterols and/or stanols [98] following research showing that over-consumption of phytosterols led to a reduction in α- and β-carotene levels in the blood [99]. Phytosterols can also prove toxic in the rare case of a genetic disease called phytosterolemia (or sitosterolemia), in which their hyper-absorption and lack of elimination lead to their accumulation [100] and metabolic disorders. French Agency for Food, Environmental and Occupational Health and Safety (ANSES) reports that in 30 % of subjects, consumption of phytosterol-enriched foods does not induce a drop in LDL-Cholesterol, and their consumption will lead to an increase in plasma phytosterol concentrations, the consequences of which on cardiovascular risk are unknown [30]. Moreover, one study revealed that in a patient consuming enriched margarine, the appearance of xanthelasma was described [36].

High dietary cholesterol intake has been implicated in atherosclerosis [101,102]. Atherosclerosis is the major cause of cardiovascular disease and its clinical complications (stroke, myocardial infarction) [49]. It is characterized by the formation of atheromatous plaques constituting inflammatory sites in the arterial wall with accumulation of lipids and fibrous elements [103]. Cholesterol metabolism is a key factor in the development of cardiovascular disease [53]. LDL-cholesterol plays a key role in the initiation and development of atherosclerosis. It corresponds to the atherogenic fraction of cholesterol, as it tends to accumulate in the arterial wall and oxidize [104]. HDL transports cholesterol from the periphery to the liver, where it is broken down. It's a "cholesterol purification" system, and therefore protective against atherosclerosis. Finally, VLDL transports endogenous triglycerides synthesized by the body, while chylomicrons transport exogenous triglycerides supplied by the diet [105]. Diets rich in trans-fatty acids are linked to higher blood levels of LDL and lower HDL. It is generally recommended to avoid large quantities of these fatty acids and hydrogenated fats, focusing on sources of polyunsaturated fatty acids [106]. Foods rich in saturated fats and cholesterol can increase LDL and total cholesterol levels. Excess weight (obesity) can increase LDL, total cholesterol and triglyceride levels. Smoking contributes to high triglycerides and low HDL levels; physical activity increases HDL cholesterol, and when parents (genetics) have high LDL, high total cholesterol, high triglycerides or low HDL, the child may inherit these conditions [95]. Obesity increases cardiovascular risk due to risk factors such as high LDL cholesterol and low HDL cholesterol [107]. Cholesterol interferes with several growth-promoting signaling pathways in cancer cells and have both proinflammatory and anti-inflammatory roles in mammals, acting via several types of immune cells, and depending on the context [108]. According to the same institute, LDL cholesterol (LDL-C) is known as "bad" cholesterol. Cholesterol is also involved in dyslipidemia, a very common metabolic pathology characterized by increased levels of triglycerides, total cholesterol, low-density cholesterol and decreased levels of high-density lipoprotein cholesterol [109]. LDL cholesterol concentration is a better predictor of cardiovascular disease risk [110]. Cholesterol is associated in many genetic diseases, such as cholelithiasis [111]. Cholesterol oxidation products were found in meats and meat products pan-fried in oil for 10 min [112]. Cholesterol can form derivatives such as oxysterols, dimers, oligomers, volatile compounds and other degraded compounds. Oxysterols may be implicated in neurodegenerative diseases such as Huntington's, Parkinson's and Alzheimer's, cancer and cardiovascular disease [113]. To guarantee consumer health, regulatory limits have been set. In addition to blood limits for total cholesterol, LDL and HDL, the *Codex Alimentarius* has set limits for levels of desmethylsterols in vegetable oils, which include cholesterol. According to the *Codex Alimentarius*, for example, the level of cholesterol in cottonseed oil, peanut oil, sesame oil, palm oil, corn oil, refined soybean oil are respectively 0.7–2.3 mg/kg, less than 3.8 mg/kg, 0.1–0.5 mg/kg, 2.6–6.7 mg/kg, 0.2–0.6 mg/kg and 0.2–1.4 mg/kg of total sterols [4].

### 3.3. *Effect of sterols on plants and environment*

Phytosterols play an important role in plant life, and are used in human and animal nutrition. In plants, phytosterols are localized in cell lipid membranes in free form [27], more specifically in the membrane lipid bilayer of plants [114]. As roles, phytosterols are involved in the stabilization of phospholipid bilayers in cell membranes [54], the rigidity and control of the fluidity level of cell membranes [115], membrane permeability [116]. Phytosterols are involved in hormone regulation, as precursors of brassinosteroids, cell membrane organization, as mediators of the interaction between proteins and membrane lipids [117], auxin transport, cell polarization, endocytosis and intercellular communication [118], cell division and differentiation [119], plant adaptation to temperature variations [120] through the elevation of phytosterol levels and HMG-CoA reductase activity during water stress indicate the role of phytosterols in stress tolerance [114]. Biotic and abiotic factors are responsible for changes in plant sterol levels [121]. Also, levels of certain phytosterols, increased in proportion to the severity of drought stress and with maturation [114] and play an important role in cell proliferation [115]. They influence plant development through the localization and functionality of key regulatory proteins [116]. It has been observed that the greater the water stress, the greater the quantity of phytosterols produced [122]. The presence of these compounds enables plants to play their full role in the environment. Consumption of plants or their by-products containing the various phytosterols also enables the animal or human species to benefit from health and nutritional advantages.

## 4. Reduction or elimination of food and body sterols

Sterol losses occur during food processing or transformation. Sterols are partially to totally destroyed during the refining process in the case of edible oils. Sterol elimination occurs during oil refining [123]. In fact, sterols are carried along with odorants during the deodorization process [124] by steam entrainment. Refining results in sterol losses for rapeseed, sunflower and soybean oil of between 29 % and 51 % and 19 % and 38 %, respectively [123]. The decolorization and deodorization stages are the most destructive of sterols [125]. As for traditional neutralization with soda, sterol losses from oils are estimated at 9.7 %. Alternative processes are used to minimize micronutrient losses. These include the use of magnesium oxide, which reduces the same sterol losses to 3.4 %, calcium hydroxide and sodium silicate as substitutes for soda [126]. Other alternatives include microwave pre-treatment of seeds to improve sterol extraction [127].

For the body, the most effective drugs against atherosclerosis are hypocholesterolemia and belong to the statin class [49]. The cholesterol-lowering effect is due to inhibition of the enzyme HMG-CoA, responsible for cholesterol biosynthesis [128]. Other molecules exist in addition to statins: fibrates reduce plasma triglyceride levels [129]. Resins increase the synthesis of bile acids from cholesterol, eliminating them via the faeces. Niacin and probucol are poorly tolerated or ineffective, and are rarely used [130]. Niacin helps to reduce circulating LDL and triglycerides while increasing HDL levels [131]. It is the most powerful drug available for increasing HDL-C levels [132]. Finally, another marketed cholesterol-lowering product is ezetimibe [133]. Several natural compounds, including terpenoids, green tea, garlic extract and curcumin, efficacious in cancer prevention and therapy, have been identified to target cholesterol homeostasis in cancer cells [134]. In relation to cancer, lowering cholesterol by various methods can effectively inhibit tumor development. The amount of cholesterol in cell membranes varies according to cell type. This may explain why the same cholesterol-lowering strategy can have opposite effects on different types of cancer [135]. Anthocyanin's, present in fruits and vegetables, beneficial effects include lowering LDL cholesterol and triglyceride (TG) levels, and increasing HDL cholesterol concentrations [136]. Inclusion of *Camellia sinensis* (green tea) by-product to broiler diets decreased blood low-density lipoprotein cholesterol [18].

Fig. 2 shows a cholesterol molecule and the chemical structures of the main phytosterols.

## 5. Sterols contribution to one health approach

One Health enables the design and implementation of programs, policies, legislation and research in which multiple sectors communicate and work together to achieve better public health outcomes. Food safety, zoonosis control and the fight against antibiotic resistance are the areas particularly concerned by One Health approach [137]. This concept is applicable to food safety, sustainable food production and environmental management. The purpose is to improve the overall health and well-being of humans, animals and the environment [23]. Food compounds of animal, human and plant play a vital role in life, through the sterols of animal (zoo sterols) and plant (phytosterols). In fact, phytosterols and their derivatives have a number of biological activities that promote the health of animals, humans and micro-organisms [29] when used within authorized limits, notably through their cholesterol-lowering effects, anti-inflammatory and antioxidant properties and the benefits they offer to the immune system [138], a reduced risk of cardiovascular disease and cancer prevention. The same applies to cholesterol, which plays an important role in the animal and human kingdoms, notably in the development of the nervous system, the formation of vitamin D [47], a precursor of adrenal and gonadal steroid hormones, participation in the constitution of bile and the structure of mammalian cell membranes, and embryonic development [87]. Altered bacterial flora could be an additional risk factor, particularly for tumors that are particularly dependent on cholesterol homeostasis [93]. In addition to cholesterol itself, cholesterol derivatives and biosynthetic intermediates play an important role in the regulation of tumor cells and the tumor microenvironment [135]. At the level of plants in their environment, several roles have been identified, including plant adaptation to temperature variations [120]. Plant parasitic nematodes are sterol auxotrophic parasites that depend on sterols in host plants for growth and reproduction. Metabolic changes in β-sitosterol and stigmasterol levels have also been associated with fungal or bacterial infections [121]. Insects and shrimps have been shown to transform phytosterols into steroid hormones or bile acids via a cholesterol intermediate [139]. Insects use sterols as structural components of the cell membrane, precursors of steroid hormones and signaling molecules [19]. For human diet example, phytosterols are present in animal products, such as ruminant milk and appear to derive from the diet of the animals [11]. Tea catechins has a hypocholesterolemic effect. Green tea decreases cholesterol synthesis and upregulates hepatic LDL [16]. L-theanine supplementation up to 200 mg/kg can improve meat quality and reduce total serum cholesterol in chickens [17]. Also, microalgae are alternative source of phytosterols for human consumption [20]. From all the above, sterols have an enormous contribution to make in the One Health concept. The benefits for human and animal health are immense, as is their important role in the life cycle of plants in their environment. Thus, the consumption of animal and plant products by humans has an impact on their health. Conversely, the consumption of plant products by animals also has an impact on their life and health.

## 6. Conclusion

Sterols are known as phytosterols in plants and zoosterol's in animals. As such, they are present in both animal and plant products. Animals and humans do not synthesize phytosterols, and must obtain them from the diet. Cholesterol is mainly a sterol present in animal and human cells, but also in small quantities in plants. In principle, endogenous cholesterol synthesis is enough for all physiological functions. Sterols are important for mammals, insects and play a part in the development cycle of plants. The consumption of plants and their by-products, in particular edible oils, are potential sources of these sterols, in particular phytosterols, whose proper use brings benefits to animal and human health. In fact, phytosterols have anti-cancer, anti-cholesterol and other properties. Also, phytosterols are essential to plant life. Cholesterol is a constituent of the human and animal body. Sterols are also important for other species such as algae and insects. However, these compounds carry risks for human health when not used within authorized limits, and require particular care in their use. High dietary cholesterol consumption has been implicated in atherosclerosis,

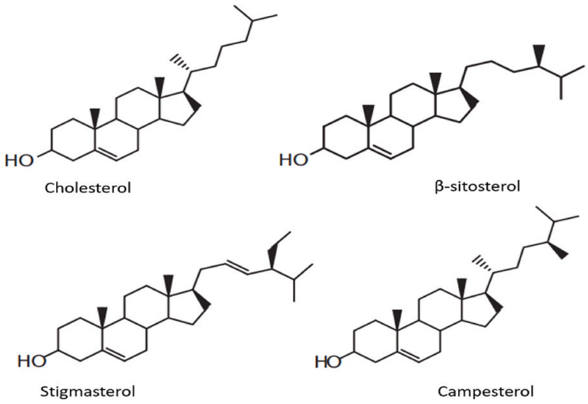

**Fig. 2.** Chemical structures of cholesterol and the main phytosterols [18]. Sitosterol, campesterol and stigmasterol are the most abundant phytosterols found in foods.

the major cause of cardiovascular disease. The same applies to phytosterols, which are responsible for phytosterolemia (or sitosterolemia). As a result, the contribution of sterols to One Health concept is important for all living beings. Indeed, sterols interact particularly with humans, animals and plants. These living beings need sterols to grow in their environment. However, this interaction in the living world is indispensable and necessary, while respecting the conditions of use established for this purpose, especially in humans. Sterols have an important contributory role to play in the One Health approach whose purpose is to improve the health and well-being of people, animals and the environment. As such, further action is essential, including in-depth research into aspects that have not yet been fully elucidated by science, and the dissemination of best practices regarding their use for good human and animal health.

## CRediT authorship contribution statement

**Souleymane Zio:** Investigation, Formal analysis, Data curation, Conceptualization, Writing – original draft. **Bakary Tarnagda:** Writing – original draft. **François Tapsoba:** Writing – review & editing. **Cheikna Zongo:** Writing – review & editing. **Aly Savadogo:** Validation, Supervision, Conceptualization.

## Ethics approval and consent to participate

Not applicable.

## Data availability statement

No data was used for the research described in the article.

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## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Not Applicable.

## List of Abbreviations

| | |
|---|---|
| MVA: | Mevalonate |
| HMG-CoA: | 3-hydroxy-3 methylglutaryl-CoA |
| LDL-C: | Low-density lipoproteins-cholesterol |
| VLDL: | Very low-density lipoprotein |
| IDL: | Intermediate density lipoprotein |
| HDL-C: | High-density lipoprotein-cholesterol |
| EFSA: | European Food Safety Authority |
| ANSES: | French Agency for Food, Environmental and Occupational Health and Safety |

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