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Natural Antioxidants: Sources, Extraction Techniques and Their Use in Livestock Production

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Natural Antioxidants: Sources, Extraction Techniques and Their Use in Livestock Production

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Abstract: Oxidative stress, resulting from an imbalance between free radical production and antioxidant defenses, can negatively impact animal health, welfare, and productivity. In livestock, diseases are often correlated with reduced antioxidant status. To mitigate oxidative stress, natural antioxidants have gained attention as alternatives to synthetic compounds. The growing need for safe and natural animal products has led to the increased use of plant food additives (PFAs) as antioxidants in animal feed. These natural sources include plant extracts, essential oils, and bioactive compounds-rich by-products. Such antioxidants can enhance product quality, oxidative stability, and shelf life in ruminants, swine, and rabbits. Additionally, maintaining a good antioxidant status positively affects meat quality parameters, including vitamin E content and reduced lipid peroxidation. This review explores the properties of natural antioxidants, extraction methods, and their significance in promoting animal welfare, performance, and product quality.

Keywords: antioxidants; natural sources; feed additives; mechanism of action; physicochemical properties

1. Introduction

Over the past two decades, the interest in natural plant feed additives (PFA) to replace artificial vitamins in livestock nutrition has increased [1]. Impressive research has been carried out to assess common substances as antioxidative ones in food items, leading to novel combinations of antioxidants and developing novel food products [2]. Antioxidants are compounds that counterweight the cell's free radicals and reactive oxygen species (ROS) [3]. Antioxidants have become scientifically interesting compounds due to their many benefits. They are still used in foods [4,5] and health [6–9]. The use of these additives can improve the efficiency of animal and poultry farming [10]. Among the sources of natural antioxidants, the most important are those from the regular consumption of vegetables and fruits. However, Asif [11] has identified other sources of antioxidants from other plants and agricultural waste. These natural antioxidants from plant materials are mostly polyphenols (phenolic acids, flavonoids, anthocyanins, lignans, and stilbenes), carotenoids (xanthophylls and carotenes), and vitamins (E and C) [2]. Presently, antioxidant substances are authorized as feed additives for prolonging the shelf life of feedstuffs based on their effectiveness in preventing lipid peroxidation. Special attention has been given, at present, to the

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ecological and effective natural antioxidant extraction techniques, to the assessment of their antioxidant activity as well as the identification of their primary dietary and herbal sources.

This review provides an overview and summarizes the natural sources of antioxidants, extraction methods, regulatory aspects, and application fields, specifically focusing on foods of animal and examining how antioxidants affect animal health, performance, and product quality [12].

2. The Natural Sources of Antioxidants

2.1. Marine Resources of Antioxidants

Diaz et al [13] reported that 90% of the planet biomass is located in the oceans, with marine species accounting for about 50% of the world total biological diversity. This large diversity of organisms is known as a store of effective molecules that are created by marine life forms to bolster their survival in a threatening environment [14]. Among marine organisms, seaweeds have been identified as an under-exploited plant resource [15,16]. Since the 1940s, the generation of algal polysaccharides has come to commercial unmistakable quality through their application as a thickening and gelling agent for several industrial applications [17]. Furthermore, it is well known that marine algae are abundant sources of biologically active chemicals with a wide range of chemical structures and promising pharmacological and therapeutic applications. According to research, chemicals derived from marine algae demonstrate a range of biological activity, including anti-coagulant [18], antiviral [19], antioxidant [20], and anticancer [21]. In recent years, diverse sulfated polysaccharides (SPs) extracted from algae seaweeds have gained much attention in the food, pharmaceutical, and cosmetic industries. SPs include a complex group of macromolecules with a great range of interesting biological activities. These polymers are chemically anionic and are common in marine algae, and animals such as invertebrates [22]. Seaweeds are the main source of non-animal SPs and their chemical structures vary among species, such as carrageenan in red algae (Rhodophyceae), fucoidan in brown algae (Phaeophyceae), and ulvan in green algae (Chlorophyceae) [18]. These SPs have displayed different biological activities beneficial to health such as anticoagulation [23], anti-HIV-1 [24], immunomodulatory [25], and anticancer [26].

Among the phenolic compounds, phlorotannins are composed by the polymerization of phloroglucinol defined as 1,3,5-trihydroxy benzene, and biosynthesized by acetate-malonate. These are highly hydrophilic compounds with a wide range of molecular sizes ranging from 126 to 650.000 Da [27]. Marine brown algae accumulate a diverse range of phloroglucinol-based polyphenols, such as phlorotannins, which could be employed as functional ingredients in nutraceuticals with potential health effects [28,29]. Among seaweeds, *Ecklonia cava*, edible brown seaweed, is a more abundant source of phlorotannins than others [30]. Phlorotannins have various biological activities beneficial to health, especially antioxidant [31], anti-HIV [32], antiproliferative [33], anti-inflammatory [34], radioprotective [35], antidiabetic [31], and antihypertensive [36]. Carotenoids are pigmented compounds generated by plants, algae, fungi, and microorganisms. They are the main natural pigments responsible for the different colors of photosynthetic organisms [37]. Nishida et al. [38] have illustrated that carotenoids have greater singlet oxygen quenching activities than α-tocopherol and α-lipoic acid and have indicated that fucoxanthin from the brown algae *Undaria pinnatifida* and *Laminaria japonica* was one of the most active compounds. Nishida et al [38] showed that carotenoids have significant singlet oxygen quenching activities compared to α-tocopherol and α-lipoic acid and indicated that fucoxanthin from brown algae *U. pinnatifida* and *L. japonica* was one of the largest active compounds. Fucoxanthin derived from the brown alga *U. pinnatifida*, is produced by hydrolysis with lipase is effective on the scavenging of 1,1-diphenyl-2-picrylhydrazyl (DPPH) and 2,2′-azinobis-3-ethylbenzene thiazolidine-6-sulfonate (ABTS) radicals [39]. Furthermore, the cytoprotective action of fucoxanthin, from a brown alga *Sargassum siliquastrum*, against H_2O_2 induced cell destruction [39].

2.2. Fruit and Vegetable Products

Due to their richness in various antioxidants, new and handled natural products (fruits and vegetables) are known for their powerful antioxidant activity. The content of different bioactive

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compounds in fruits and vegetables is related to the nature of the raw material. Products including fruits, vegetables, coffee, tea, herbs, and spices include polyphenolic substances such as flavonoids, phenolic acids, lignans, and stilbenes. Flavonoids include anthocyanins, which are found in berries, as well as flavonols (kaempferol, quercetin, and myricetin), flavanols (catechin, epicatechin), which are found in cocoa, dark chocolate, green tea, and black tea [40]. Betalains, found in red beets, cactus pears, pitaya, and amaranth [41], and chlorophylls, prevalent in green leafy vegetables [42], are other substances with strong antioxidant capabilities. The consumption of berries has recently increased due to the high levels of polyphenols, which are known to have health benefits. Blueberries had greater levels of anthocyanins, flavonols, and phenolic acids, while Strawberries had higher levels of flavan-3-ols, dihydrochalcones, and flavanones. Anthocyanins were the most important phenolic constituents of both berries. Additionally, the higher total phenolic content of blueberry jam justified their higher antioxidant capacity as determined by the DPPH free radical assay, compared to strawberry. Among the different plants, natural products, and vegetables (PNPVs) are known to supply health benefits [43–45]. PNPVs, such as citrus fruits (oranges, grapefruit, lemons, and limes), grapes, pomegranates, apples, dates, green and yellow vegetables (peppers), cabbage, strawberries, carrots, green leafy vegetables, and bananas [46] are known globally to contain antioxidants. Antioxidants are recognized by their both added substance and synergistic activities in minimizing the hazard of chronic diseases [47]. Hence, fruits and vegetables have protective functions against cardiovascular diseases. In general, the defending role of PNPVs has been assigned to their antioxidant components (natural radical terminators) such as vitamins A, C, and E (α-tocopherol), β- and α-carotene, and glutathione [48]. Other antioxidants such as alkaloids, terpenoids, sulfur compounds, and phenolic and polyphenolic compounds were found in PNPVs (Table 1) [49], reducing oxidative damage by scavenging free radical activities [50]. Moreover, these bioactive, non-nutritive plant compounds, for the most part, assigned as phytochemicals, contribute to the end-of-chain responses by disposing of free radical intermediates [48]. Niki and Noguchi [51] reported that carotenoids, an extremely important bioactive compound present in PNPVs, are especially compelling in avoiding oxidation. Another group of bioactive compounds such as polyphenolic flavonoids is plant metabolites with multiple organic and pharmacological properties [52,53].

2.3. Medicinal Plants

Natural products, particularly those based on plants, have been seen as important therapeutic alternatives [54] due to their richness in a wide variety of secondary metabolites with antimicrobial and antioxidant characteristics [55]. Among these secondary metabolites' pharmacologically bioactive constituents are alkaloids, flavonoids, tannins, anthraquinones, and phenolic chemicals. *Cistus monspeliensis* and *Globularia alypum* are two Mediterranean-wide shrubs [56]. The phytochemical examination illustrated that *G. alypum* and *C. monspeliensis* were wealthy in different compounds such as polyphenols, tannins, and flavonoids, which justifies their biological activities [57]. In recent years, numerous researchers have described a comprehensive study on the qualitative structure of medicinal plant extracts. The chem profile of the genus Cistus was extremely variable due to geographical regions, subspecies variance, and then soil-climatic conditions due to seasonal variations. The genus Cistus phenolic composition has been widely investigated and characterized by citing *Cistus laurifolius*, *Cistus incanus*, *Cistus parviflorus*, *Cistus salvifolius*, *Cistus libanotis*, and *Cistus creticus* [58]. In the meantime, the extract of *C. monspeliensis* was found to contain numerous compounds from distinctive chemical classes such as flavonoids, coumarins, terpene derivatives, and hydrocarbons. The main compounds identified were isorhamnetin-*O*-rutinoside, isorhamnetin hexoside deoxyhexoside, and chrysoberyl di-glucoside [59]. Thus, the chromatograms of the ethanolic extract of *G. alypum* disclosed a wide range of compounds; the most relevant are isorhamnetin-*O*-rutinoside, naringenin glucoside, tetragalloyl hexoside, myricetin, and I3, II8-Biapigenin [59]. The medicinal plant *Aspilia africana* is owned by the Asteraceae family and their leaves and roots have been exploited to treat many diseases such as wounds, osteoporosis, sores, malaria cough, febrile headache, wounds, gonorrhea, ear infections, stomachache, rheumatic pain, tuberculosis, measles, diabetes, diarrhea, gastric ulcers, and inflammatory conditions [60–62]. The

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polyphenolic chemical class is primarily responsible for its antioxidant, anti-inflammatory, wound-healing, anticancer, antidiabetic, and antiulcer actions [60,61].

2.4. Agro-Industry Waste

Energy production from waste is an encouraging line. From the perspective of environmental sustainability, the usage of agro-industrial waste residues as feedstock for biorefinery processes has gained extensive consideration. In agro-industry, diverse biomasses are uncovered into assorted unit forms to offer esteem to different agro-industrial wastes. Agro-industrial waste can provide a substantial number of valuable products such as fuels, chemicals, energy, electricity, and by-products [63]. Agro-waste from coffee is a fantastic source of polyphenols with antioxidant activity and a variety of uses in the food and cosmetic industries. Because of the large concentration of allegedly harmful compounds in these by-products, managing them remains difficult in the industrial setting [64]. in several reviews, coffee pulp and parchment have been explored as raw materials for obtaining antioxidant compounds for cosmetic preparations [65,66], for the fabrication of new composite materials [67], and for water bioremediation [68,69]. Antioxidant compounds, and in particular phenolic acids, can be isolated from agricultural coffee waste and combined with the coffee process chain as a value-added by-product, with commercial relevance as food additives [70]. The onion (*Allium cepa L.*) is consumed raw as well as prepared in a variety of ways, including baking, boiling, braising, grilling, and frying [71]. Recently, onion production has increased by 25% worldwide [72,73], which is related to both the usage of onions as a source of bioactive phytonutrients [72] as well as their prospective use as a flavoring or spicy element. Many researchers showed that onions are a wealthy source of antioxidant compounds, to prevent oxidative stress [71,74]. Several epidemiological research studies have supported that the consumption of onions decreases the incidence of different forms of cancer, as well as cardiovascular and neurodegenerative diseases [71,74]. As well, onion waste has considerably enhanced as indicated by the high number of associated scientific reviews in the last two years. The residual biomass is composed mainly of the skin, bark, husk (the outermost layers), roots, bulb tops, and deteriorated bulbs [73,75,76]. Nevertheless, the onion skin is the main waste product of onion processing (up to 60%) [73]. Onion peel is rich in polyphenolic antioxidants, especially quercetin, glucosides, belonging to the group of flavonoids, and ferulic acid, gallic acid, and kaempferol, which exhibit significant beneficial properties associated with different biological activities [77].

3. Extraction Techniques of Antioxidants

Extraction is a critical step in the investigation of natural antioxidants. Extraction processes represent an important step in producing antioxidants from food and medicinal plants [78,79]. According to Awad et al. [80], the extraction conditions and the processing protocols such as solvent, time, temperature, and plant powder should be optimized to obtain the optimum yield with the maximum concentration of active ingredients. Various extraction procedures including green non-conventional methods have been developed to improve the efficiency of antioxidant components extraction from plant materials. [81,82]. Among the conventional extraction methods, aqueous extraction consists of extracting volatile organic and non-organic compounds with distilled water. This technique involves three processes: hydro-diffusion, hydrolysis, and decomposition by heat, and does not involve organic solvents [83]. It can be used in combination with non-conventional technologies to increase the yield of volatile compounds [84]. However, maceration in solvents and Soxhlet extraction are simple, low cost, and fast [85], but they take a long time and require a lot of organic solvents, which have poor extraction yields [86,87], and ultrasound extraction or modern methods such as supercritical and subcritical extraction and pressurized liquid extraction [88–90]. Unconventional and environmentally friendly methods (ultrasonic, microwave [91], and pressure extractions [92]) have been developed to replace conventional methods. They have been connected alone or in conjunction with the use of solvents, to decrease energy and solvent prerequisites [93].

It is alluring to have a better yield together with a noteworthy concentration of active compounds. Pressurized liquid extraction, supercritical fluid extraction, high hydrostatic pressure

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extraction, pulsed electric field extraction, and high-voltage electrical discharge extraction are new efficient ultrasound-assisted extraction techniques developed to increase extraction yields and decrease energy consumption [93]. Microwave-assisted extraction (EMA) of polyphenols was performed by Dahmoune et al. [94]. EMA has been shown to have several advantages over conventional extraction methods, including higher extraction yield, lower solvent consumption, and shorter extraction time [95]. These modern techniques are very effective and can be categorized as "green extraction" techniques [96,97].

Table 1. Summary of the natural antioxidants and their sources.

Sources	Origin	Phytochemical class	Antioxidants	References
Marine sources	-Brown algae	-Polyphenols	- Phlorotannins	[31]
	- *Undaria pinnatifida* - *Laminaria japonica* - *Sargassum siliquastrum*	- Carotenoids	- Fucoxanthin	[39; 40]
	- Brown algae (Phaeophyceae) -Red algae (Rhodophyceae) -Green algae (Chlorophyceae)	Sulfated polysaccharides (SPs)	- Fucoidan - Carrageenan -Ulvan	[18]
Medicinal plants	*Cistus monspeliensis*	Phenolics acid	Caffeoyl shikimic acid, 3,4-dihydroxybenzoic acid-*O*- hexoside	[64]
		Flavonoids	Amentoflavone	
	Globularia alypum	Phenolics acid	Sinapic acid derivative	[64]
		Flovonoids	Myricetin, Kaempfreol glucoside, Liquiritin, Amentoflavone	
	Aspilia africana	Phenolics acid	Chlorogenic acid	[98]
		Vitamins	ascorbic acid, riboflavin, thiamine	
fruit	Apple	Sterols	Campesterol, β-sitosterol	[99–103]
		Anthocyanins	Cyanidin, delphinidin	
		Flavanols	Catechin	
		Flavanols	Quercetin, kaemferol	
		Dihydrochalcones	Phloretin	
		Hydroxycinnamic acids	Ferulic acid, chlorogenic acid	
		Salicylates		
	Berries	Hydroxybenzoic acids	Gallic acid	[54,99]
		Flavanols	Catechin	
		Flavonols	Quercetin, kaempferol	
		Anthocyanins	Cyanidin, delphinidin	
		Stilbenoids	Resveratrol, pterostilbene, piceatannol	
	Banana	Hydroxybenzoic acids	Gallic acid	[54,99–103]
		Flavanols	Catechin, epicatechin, epigallocatechin	
		Flavonols	Myricetin	
		Lignans	Pinoresinol	

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		Sterols	Campesterol	
vegetable	Broccoli	Sterols	Campesterol, β-sitosterol	[99,100,104–106]
		Carotenoids	α-carotene, β-carotene, lycopene, xanthophylls	
		Quinones	Phylloquinone, menadione	
		Tocopherols & tocotrienols	α-tocopherol, β-tocopherol, α-T3, β-T3, α-tocotrienol, β- tocotrienols	
		Sterols	Sitosterol, β-sitosterol, sitostanol, campesterol, brassicaterol, stigmasterol, campestanol	
		Anthocyanins	Cyanidin,	
		Condensed tannins	Procyanidin A1, procyanidin B2	
		Glucosinolates	Progoitrin, sinigrin, glucoiberin, glucoraphanin, glucoalyssin, gluconasturtiin, gluconapin	
	Onion	Glycoalkaloids	α-solamargine, α-solasonine	[99]
		Sterols	Campesterol, β-sitosterol	
		Thiosulfinates	Allicin	
		Anthocyanins	Cyanidin, delphinidin	
		Flavonols	Quercetin, kaempferol	
	Spinach	Phenolic terpenes	Vitamin E	[99]
		Carotenoids	α-carotene, β-carotene, lycopene	
	Brussels sprouts	Carotenoid	β-carotene	[104–111]
		Tocopherols and tocotrienols	α-tocopherol, β-tocopherol, α-T3, β-T3, α-tocotrienol, β- tocotrienols	
		Glucosinolates	Progoitrin, sinigrin, glucoiberin, glucoraphanin, glucoalyssin, gluconapin, gluconasturtiin	
Agro-industry waste	Coffee	Anthocyanins	Delphinidin 3-*O*-(6″-acetyl-glucoside), Peonidin 3-*O*-(6″-acetyl-glucoside), Cyanidin 3-*O*-(6″-malonyl-glucoside)	[63]
		Catechins	(+)-Catechin	
		Flavones	Apigenin	
		Hydroxybenzoic acids	Gallic acid 4-*O*-glucoside, Gallic acid 3-*O*-gallate, Gallic acid	
		Hydroxycinnamic acids	Caffeoyl aspartic acid, Caffeic acid 4-*O*-glucoside, Chlorogenic acid	
	Onion husks	Flavonols	Quercetin, 3′-Methoxy-4′,5,7-trihydroxyflavonol, Laricitrin	[112]
		Flavanonols	Taxifolin	
		Flavonoid-*O*-glycosides	Quercetin-3,4′-*O*-di-◎-glucoside, Isoquercitrin	
		Isoflavones	Tectorigenin	

4. Antioxidant Properties

An antioxidant could be a substance able to avoid the oxidation of other molecules [113]. The natural antioxidants are principally polyphenols (phenolic acids, flavonoids, anthocyanins, lignans, and stilbenes), carotenoids (xanthophylls and carotenes), and vitamins (vitamin E and C) [114,115]. Phenolic compounds present a diversified structure, ranging from simple molecules (ferulic acid, vanillin, gallic acid, and caffeic acid) to polyphenols (tannins and flavonoids) [116,117]. The most

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important Vitamins are vitamins E and C. Vitamin C is fat-soluble and composed of a group of chemical compounds consisting of four tocopherols and four tocotrienols, which include four isomers (α, β, γ, and δ) [118]. In choosing natural plant extracts for human diets, the organoleptic qualities of the food product are considered [119]. Many studies have shown that antioxidants have LD50 values lower than 1000 mg/kg body weight, and ought to not have any critical impacts on animal performance [120,121].

Natural antioxidants respond with free radicals or precursor metabolites changing over them into less responsive molecules and anticipating or postponing the oxidation of natural molecules. The most important and well-characterized natural antioxidants in the animal body are vitamins E and C. When the antioxidant system finds itself in high-stress conditions, if free radical production is increased dramatically, then without external help it will be difficult to prevent damage to organs and cells. Increased dietary supplementation with natural antioxidants, particularly minerals like selenium, can offer this external assistance. Given that antioxidants are often expensive dietary components, it can be difficult for nutritionists or feed formulators to determine whether the antioxidant team in an animal body needs assistance and how much of this assistance might justify additional feed costs. The following are a few examples of potential pressures in the production of poultry [122].

Antioxidants shield physiologically significant molecules, such as DNA, proteins, and lipids, against deterioration [123]. Supplementing with more antioxidants to increase meat quality while it's being stored [124]. Combining vitamin E and selenium can significantly minimize drip loss [125]. Due to reduced vitamin E in the diet, the drop in egg production brought on by heat-related stress is increasing. Boost antioxidant intake. Mycotoxin toxicity was lowered by supplementation. provide the body's immunological system with good assistance [126].

The study's findings led to the conclusion that antioxidants (vitamins E and S) may be combined with a baseline diet to get the greatest outcomes in terms of body weight increase. The superior performance may be attributable to the vitamins' combined synergistic effects on the birds' physiological systems [127]. Numerous studies have demonstrated that natural antioxidants contain antioxidant, anti-inflammatory, metabolism- and immunity-modulating properties, as well as anthelminthic, anti-methanogenic, and antibacterial actions that are particularly significant in the production of cattle. These traits encourage research and education on these secondary metabolites' potential applications as organic tools to improve animal performance and the quality of animal products [128].

5. Use of Antioxidants in Livestock Production and Their Effect on Animal Health, Performance, and Product Quality

Animals are frequently subjected to a variety of oxidative stress circumstances that can influence animal health, decrease growth performance and production, and ultimately damage economic profitability. The addition of antioxidants to animal diets would be an important nutritional strategy to mitigate the negative effects induced by oxidative stress conditions [129]. The addition of antioxidants as nutritional supplements in animal diets is a common practice to improve animal performance, health, and welfare [130]. The use of antibiotics in animal production affects human and animal health, as well as the safety of animal products [131]. Phytogenic feed additives have been used as alternatives to antibiotics for their potential effects in enhancing growth performance and quality characteristics of the derived products including meat, milk, and eggs [132]. During oxidative stress, unfavorable substances, including malondialdehyde (MDA), lipid peroxides (LPOs), and carbonyl protein complexes could be formed and consequently cause organism damage and meat quality deterioration [133]. Thus, feeding an animal with exogenous antioxidants provides oxidative stability, sensory quality, and the acceptability of derived products [134]. Recently, numerous studies showed that polyphenol compounds, due to their contents of secondary metabolites, could maintain an antioxidant capacity as an important factor in animal health and exert their favorable effects in improving performance [133,134].

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5.1. Ruminants

To prevent oxidative food deterioration, antioxidants have been widely employed as food additives for cattle, sheep, and goats. They are also known to stop the development of fungi and the formation of mycotoxin linked to many toxic Fusarium species [135].

In bovine production, especially, in herds that had managed contagious mastitis, vitamin E and selenium were associated with the prevalence of clinical mastitis and bulk tank Somatic cell count (SCC). Low bulk tank SCC and lower rates of clinical mastitis were linked to high serum Se levels. Up until cows ingested more than around 5 mg of selenium daily, the levels of selenium in blood and the feed were positively correlated [136]. Se consumption had little effect on serum Se levels above this point. The percentage of clinical mastitis was adversely linked with the concentration of vitamin E in the diet. Vitamin E consumption was favorably correlated with plasma vitamin E concentrations, however in dry cows as opposed to nursing cows, it had a stronger impact on serum vitamin E values [137]. On the other hand, Malmuthuge and Guan [138] studied the effect of rumen protective glucose (RPG) supplementation on hepatic oxidative/antioxidant status and protein profile. In early postpartum cows, which may be at high risk for hepatic metabolic problems, many studies demonstrated that RPG decreased insulin sensitivity but raised triglyceride levels and oxidative stress. A study by Kong et al. [139] Showed the importance of using the culture of Acremonium terricola (ATC) or ATC as a new feed additive in the diet of dairy cows. Indeed, ATC improved milk production and protein content. Kong et al have suggested that this is strongly linked to an improvement in the immune system and the antioxidant capacity of ATC.

5.2. Poultry

The internal content of antioxidants that slow down the oxidative effects in meat may be increased naturally by adding natural antioxidants to feed [133]. Rosemary (*Rosmarinus officinalis L.*), which influences the further preservation of chicken meat and semi-finished products derived from it, is one of the sources of natural antioxidants for the poultry sector. *In vivo* tests revealed that grape seed extract prevents the oxidation of chicken lipids during stomach digestion [140].

Antioxidants in liposomal form boosted the detoxifying capacity of laying hens and decreased the levels of xenobiotics, nitrites, and nitrates. The increased excretion of heavy metals from chicken bodies also avoided the buildup of residual heavy metals in the diet. The primary physiological and productivity markers of broiler chickens changed favorably when the liposomal nanoform of silymarin was added to their diet [141]. Wang et al [142] found that oxidative stress can decrease ovarian function, and egg-laying performance, and affect body metabolites in the layered model. They then showed in their study the ameliorating effect of melatonin on ovarian oxidative stress, via the SIRT1-P53/FoxO1 pathway. Adeyemi et al. [143] evaluated the effect of onion leaf powder as an antioxidant source on growth performance, immune indices, and meat quality in a broiler diet. Interestingly, results showed a significant increase in catalase, glutathione peroxidase, and total antioxidant capacity, and a decrease in drip loss, malondialdehyde, and carbonyl content in breast meat. Moreover, Saracila et al. [144] demonstrated the beneficial effect of dietary supplementation with a combination of some antioxidants (chromium picolinate with vitamin C, Zinc, and creeping wood sorrel powder) on the health and meat quality traits of chicken. In the other study, Mahrous et al. [145] investigated the effect of different levels of clove supplementation in a broiler diet. Indeed, the best immune response and antioxidant status were obtained with the supplementation of 1 g of clove/kg. Similarly, serum cholesterol and muscle MDA levels were significantly reduced. Therefore, provide a healthy broiler's meat that is favorable to human consumption. In the same context, Hussein et al. [146] stated that dietary supplementation with clove (*Syzygium aromaticum*) oil with a dose of 1.5 mL/kg diet could improve growth performance, enhance health status, and decrease intestinal pathogens in Japanese quails. Furthermore, the study of Moustafa et al. [147] showed that dietary supplementation of essential oils (thyme, clove, and cinnamon) at 100 mg/kg significantly improved productive traits (body weight, body weight gain, FCR), and improved antioxidant status of broiler chickens. Abbassi et al. [133] revealed the decrease of lipid oxidation in meat with the supplementation of a broiler diet with different sources of antioxidants (Vitamin E, rosemary, and

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Tyme). Additionally, carnosine as an antioxidant can be efficiently utilized in chicken diets as a natural source of antioxidants and immunostimulants. Cong et al. [148] showed that carnosine supplementation in the animal diet improved meat quality, and antioxidant activity and decreased the lipid peroxidation status of breast meat.

5.3. Pigs

Several natural antioxidants are available for use in the swine industry [149]. Many studies showed that the incorporation of antioxidants in the diet of pigs can reduce the negative effects of lipid peroxidation [150,151]. To protect animals from oxidative stress and maintain early postweaning growth rates, Orengo *et al.* [150] recommended adding antioxidants to the postweaning diet of piglets, and they reported that antioxidants can complement growth performance. Along the same lines, Lu *et al.* [152] found that the dietary addition of natural antioxidants was effective in improving growth. On the other hand, There is evidence, in swine, that antioxidants improve the immune status [153,154] and have potential health benefits for both animals and consumers [155]. A study by Su et al. [156] reported that supplementing the diet of weaned pigs with antioxidants increased body weight gain (BWG). In addition, serum IgG, and IgA increased. Similarly, Malondialdehyde (MDA) decreased in serum, jejunal mucosa, and pancreas, and glutathione (GSH) significantly increased in serum, the duodenal mucosa, and ileal mucosa.

5.4. Horses

During stressful conditions in horses, including exercise, the body's antioxidant levels must be adapted to cope with the ROS resulting from increased oxygen consumption [157]. Horses competing in races are prone to antioxidant deficiencies [158,159]. Depending on the horse's condition, it is needed to supplement with antioxidants [160]. Antioxidant supplementation before stress (travel, competition, etc.) in horses is known to be potentially beneficial to horses by enhancing immune function and protecting muscle and nerve cells [161]. Antioxidants have been shown to protect against equine protozoan myeloencephalitis (EPM), equine degenerative myeloencephalopathy (EDM), and fatigue during exercise in equines [162,163].

6. Conclusions

Increasing interest has been observed over the past decade in exploring the natural ingredients to be used in food and food products. Antioxidants play a key role in immune responses, cell signaling processes, transcription factor activities, and gene expression. The literature reports compiled here will be beneficial to identify the significance of various natural sources based on their antioxidant capacity, active ingredients, and geographic availability.

A natural alternative to traditional synthetic antioxidants to use as preservatives for livestock products is becoming preferable since until now the harm for the consumer from the action of natural antioxidants in comparison with synthetic ones has not been proved: natural antioxidants effectively slow down lipid oxidation. New research findings have revealed the effectiveness of dietary antioxidants in mitigating oxidative stress in livestock.

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