



GRAPE SEED OIL: HEALTH BENEFITS AND USEFUL IMPACTS ON LIVESTOCK PERFORMANCE AND PRODUCTS QUALITY – A REVIEW

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Abstract

Grape seed oil (GSO) is a rich source of unsaturated fatty acids, antioxidants, and phenolic compounds that have been shown to affect physiological disorders associated with chronic diseases positively. The article demonstrates GSO's chemical structure and health benefits, including its ability to alleviate oxidative stress, modulate cytokines, exhibit antimicrobial activity, and potentially prevent cancer. The review highlights the positive impact of GSO on livestock growth and products quality, particularly when combined with grape pomace in broiler and rabbits diets. Including grape seed extract in animals' diets improved carcass traits under oxidative stress conditions. It may also help reduce total lipid levels and lower LDL cholesterol levels, benefiting heart health. The article emphasizes the need for more studies to better understanding of the optimal bioactivity of GSO and to determine the recommended doses of GSO for human consumption. The review suggests that GSO could be a promising natural feed additive for improving poultry health and product quality.

Key words: grape seed oil, antioxidative status, carcass traits, growth, meat quality, blood parameters, livestock

One of the most significant fruits in the world, grapes have a wide range of applications, including raw food or in creating foods and beverages (raisins, wine, juice, jam, vinegar, jelly, and seed oil). Due to their nutritional properties, the berries of *Vitis vinifera* L. ssp. *sativa* grapes have gained attention from people worldwide. This includes the original products (raw and dried fruit) and compounds like peel and seed extracts (Bail et al., 2008). Grape seed extract, either alcoholic or aqueous, has a higher level of antioxidants and advantageous benefits such as controlling the expression levels of antioxidative enzymes, preventing oxidative cell damage, having antiatherosclerotic and anti-inflammatory actions, and preventing specific forms of cancer in both human and animals (Wang et al., 2009; Brasky et al., 2011; Pérez et al., 2015; Garavaglia et al., 2016).

Grapes are among the world's most extensively produced crops because of their nutritious qualities, particularly their high number of polyphenols. An important nutritional supply with potential for application in biotechnology for both human and animal feeding, grape pomace makes up around 20–30% of the residue left over

after the manufacturing of wine (Polo et al., 2023). In addition to being a cheap source of bioactive composites, grape pomace is a great substitute for synthetic antioxidants and addresses the issue of waste pollution in the environment (Antonić et al., 2020).

Grape seeds are a component of grape pomace with an average of 6% to 20%; this oil is typically extracted using solvents and purified before use (Iuga and Mironnea, 2020). One way to profit from this by-product with higher nutritional values is by recovering grape seed oil (GSO) (Pardo et al., 2009). Owing to GSO's widespread production, it is used in many products for humans and animals such as the pharmaceutical and cosmetics industries (Górnaś et al., 2018) (Figure 1). Similar to vegetable or olive oil in characteristics, GSO may provide users with various health advantages such as hypolipemic and hypotensive activity because of their high mono-unsaturated and polyunsaturated fatty acids (Kaseb and Biregani, 2016). During batch frying, it has a moderate flavor with fruity undertones, a high-level smoke point (216°C), decent digestion, and a slight viscosity rise (Yang et al., 2021). Grape seeds contain certain unsatu-

rated fatty acids, including oleic and linoleic acids, which comprise more than 89% of the oil's overall makeup. Oil content in grape seeds ranges from 8% to 15% (w/w). The significant amount of these fatty acids in grape seed oil has several benefits for use by humans. It contains high quantities of linoleic acid, which is necessary for prostaglandin production and controls platelet activation and inflammatory reactions, and high levels of vitamin E, which lowers the danger of arteriosclerosis and lowers cholesterol levels (El-Saadany et al., 2022, Garavaglia et al., 2016).

Grape seed oil possesses hepatoprotective, neuroprotective, and hepatic cholesterol-lowering effects, which may help prevent heart and circulation problems. When rats with damaged liver and brain were fed GSO (Figure 2), the liver was protected against acute harm. The oil's strong anti-inflammatory, antioxidant, and antiapoptotic characteristics were responsible for this outcome (Yang et al., 2021). To protect the brain from oxidative stress and inflammatory cascades, GSO may be able to neutralize free radicals, boost antioxidant enzyme activities, decrease xanthine oxidase gene transcription, suppress inflammatory responses, and inducible nitric oxide synthase (Singh et al., 2022). Moreover, rats given GSO showed favorable effects on liver cholesterol levels, rats'

acceptability, and reduction in feed consumption (Rubio et al., 2020; Zhang et al., 2021).

This article aimed to review the chemical structure, mode of action, and general medicinal properties of GSO. Additionally, the health benefits of GSO on livestock performance and product quality was also highlighted particularly for broilers and rabbits. To write this narrative review article, information was collected from 159 original researches and review articles. MEDLINE and PUBMED database as well as handsearching were used to collect data from 1999 to January 2023. Key words were grape seed oil, antioxidative status, carcass traits, growth, meat quality, blood parameters, and livestock. In addition, personal and college libraries searching for texts on the health benefits of grape seed oil were also used.

Chemical structure

Grape seeds are a treasure trove of polyphenols, including phenolic acid, flavonoids, and anthocyanins (Amer et al., 2014). The proanthocyanidin extract of grapeseed is more concentrated in polyphenolic antioxidants than grape skins, and condensed tannins are also found in different veggies and fruits (Hassan et al., 2014; Hajati et al., 2015; Mansouri et al., 2015).

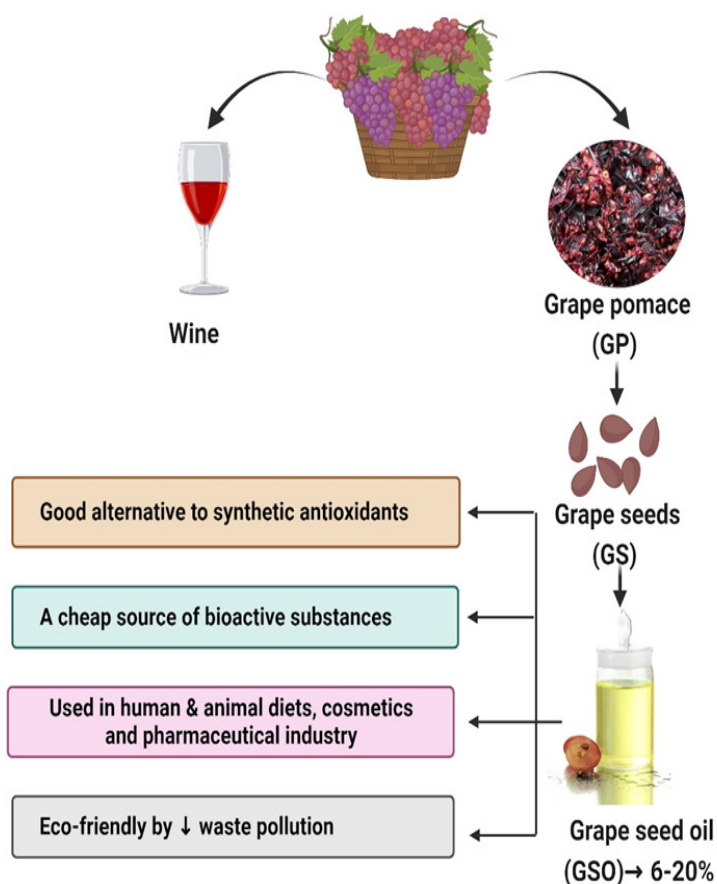


Figure 1. Grape seed oil production after the wine manufacture

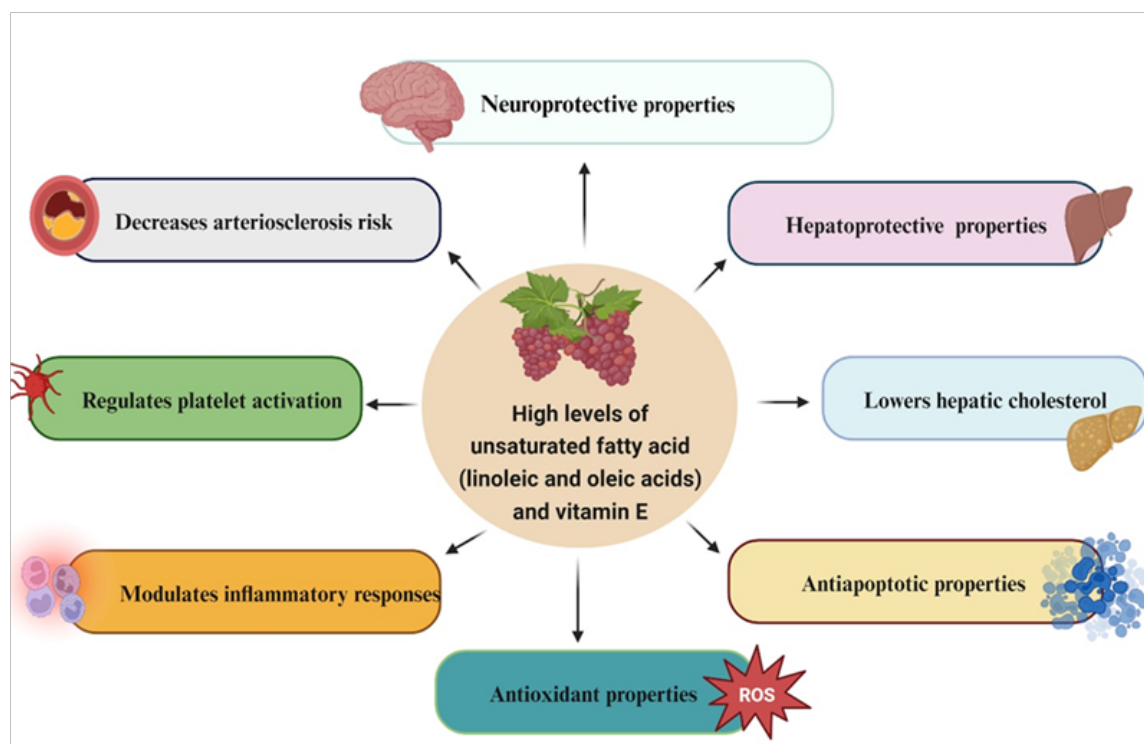


Figure 2. Grape seed oil general activities

Research has proven that extracts from grapeseed and pomace provide natural antioxidant benefits to rabbits, rats, and broiler chickens (Choi et al., 2010; Dorri et al., 2012; Amer et al., 2014; Mansouri et al., 2015; Yonguc et al., 2015). Grape by-product extract has been viewed as a possible source of antioxidants, offering a novel antioxidant choice for animal nutrition (Gladine et al., 2007). Grape seeds contain up to 16% essential oil, 40% fiber, 11% protein, 7% polyphenols such as tannins, and other materials such as sugars and minerals (Ma and Zhang, 2017; de Campos et al., 2008), phosphorus is the main mineral present in grape seeds. Furthermore, they include a variety of fatty acids with linoleic acid dominating the group. Other significant fatty acids include oleic, myristic, palmitic, and stearic. Additionally, the grape seed oil is a composition of polyunsaturated fatty acids, linoleic acid, omega-6 fatty acids, antioxidants, and vitamin E (Hussein and Abdrabba, 2015). Notably, it contains more vitamin E than other commonly used oils, such as olive oil, thus making it an advantageous addition to a healthful diet (Yonguc et al., 2015).

Mode of action

This section focuses on exploring the possible benefits of GSO, which originates from the winery industry remains, berries, seeds, and extracts. Reports of the bioactivity of these accessible by-products have raised interest in the oil's potential dietary supplement usage as a preventative measure or therapy for chronic illnesses (Garavaglia et al., 2016; Shinagawa et al., 2017). Still, many queries, such as bioavailability, dosage response,

and human side effects, remain unresolved (Kaseb and Biregani, 2016; Ebrahimi-Mameghani, 2020). Despite this, we shall evaluate the principal nutraceutical activities connected to the several elements of GSO.

Common reactive oxygen species (ROS) including hydroxyl radicals, superoxide, and hydrogen peroxide are produced physiologically to serve as signaling molecules that support the control of homeostasis and the immune system. Antioxidant enzymes including catalase, glutathione peroxidase, and superoxide dismutase regulate this system. An imbalance between antioxidants and ROS caused by excessive ROS production is known as oxidative stress. As a result, grape and its byproducts include many phenolic compounds with anti-inflammatory and antioxidant properties, including resveratrol, quercetin, procyanidins, and others (Xia et al., 2010). Additionally, phytosterols, which are also lipophilic substances mostly present in grape seed oil, may inhibit the release of proinflammatory mediators by oxidized low-density lipoprotein-stimulated macrophages during oxidative stress and eicosanoid production (Shinagawa et al., 2015; Vivancos and Moreno, 2008).

Medicinal properties of grape seed oil

Antioxidant activity

Grapes possess phenolic compounds that work as natural antioxidants, with more abundant concentrations in grape seeds and their extraction (Figure 3). However, the hydrophilic phenols constitute a small portion of its oil (Khurana, 2013; Fernandes et al., 2013). Nevertheless, oil extraction techniques may be manipulated to enhance

phenol yields in the future (Maier, 2009; Rombaut et al., 2015), emphasizing the need for new natural compounds that may aid in decreasing oxidative stress, destroying free radicals, controlling lipid oxidation, and diminishing the presence of hydroperoxides in today's diseases (Shinagawa et al., 2017).

Among the phenolic components in GSO with anti-oxidant bioactivity are catechin, gallic acid, epicatechin, tannins, and procyanidins (Garavaglia et al., 2016). In addition to fatty acids, other lipophilic substances found in GSO, such as vitamin E and phytosterols, are also known to have antioxidant action (Choi and Lee, 2009). Furthermore, some evidence indicates that vitamin E may help prevent aging and the effects of chronic illnesses (Fernandes et al., 2013).

Collectively, phenolic compounds and vitamin E, which is abundant in grapeseed oil and has strong anti-oxidant qualities, have been found to help the body repair free radical-damaged cells. Some malignancies and heart disease are prevented by this defense.

Anti-inflammatory activity

It has been discovered that GSO, which contains both hydrophilic and lipophilic components, aids in reducing inflammation in chronic conditions. Studies on animals have demonstrated that consuming GSO may alter inflammatory markers like cytokines (Shinagawa

et al., 2017). Arachidonic acid (AA) release, cytokine synthesis, NO (nitric oxide) synthase activity, and other anti-inflammatory gene expression have all been linked to phenolic chemicals contained in GSO (Santangelo et al., 2007). According to cell lines, the vitamin E isomer tocotrienols may similarly affect the adipose inflammation associated with obesity (Zhao et al., 2015). The phytosterol β -sitosterol, which is included in GSO, may also prevent macrophage cells triggered by oxidized low-density lipoprotein (LDL) from releasing pro-inflammatory mediators that harm the generation of eicosanoids and oxidative reactions (Shinagawa et al., 2015 a; Vilahur et al., 2018). According to recent studies, linoleic acid has anti-inflammatory properties for mammalian cells (Kolar et al., 2019). Linoleic acid from GSO is a promising nutraceutical for human use as well as animal studies have shown that GSO possesses anti-inflammatory and antioxidant characteristics, contributing to its hepatoprotective and neurological properties (Ismail et al., 2015, 2016). Besides, the GSO's hydrophilic components may reduce oxidative stress and inflammation in human cells (Millan-Linares et al., 2018). Collectively, inhibiting the release of AA, NO, and other cytokines, which is necessary for the synthesis of leukotrienes and prostaglandins, which in turn triggers the inflammatory response, is one advantage of the polyphenols found in GSO.

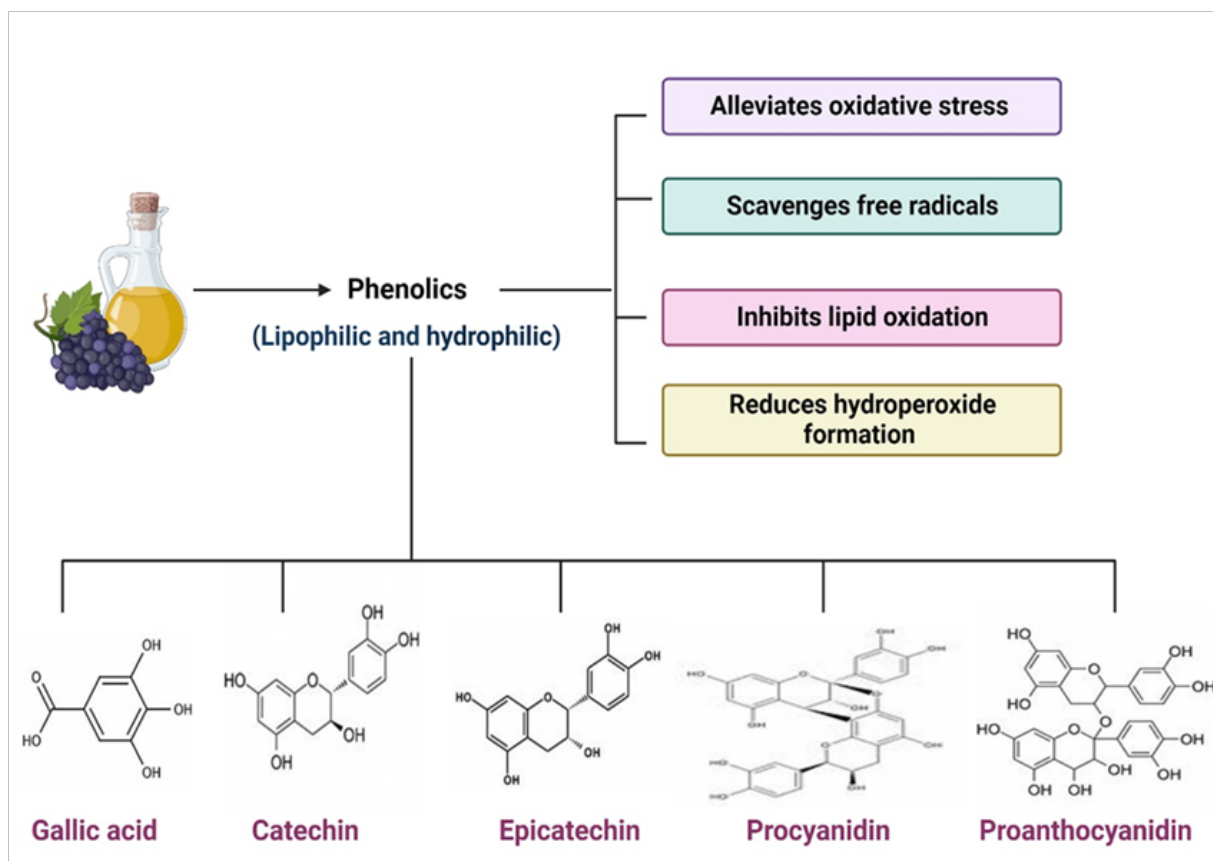


Figure 3. Antioxidant activity of GSO

Antimicrobial activity

Some bacteria, including *Staphylococcus aureus* and *Escherichia coli*, have been observed to be resistant to the antimicrobial effects of GSO (Garavaglia et al., 2016). The phenolic substance resveratrol present in GSO is a crucial factor in oxidative damage to bacterial plasma membranes. Many people want to employ GSO or its constituent parts as adjuvants in antimicrobial therapy. According to Shrestha et al. (2012), grape seed extract had a modest effect on *S. aureus* but had little to no inhibitory effect on yeast and Gram-negative microbes. When mixed with propylene glycol and polyethylene glycol, grape seed extract also displayed a dose-dependent inhibitory action on *S. aureus*.

Additionally, grape seed oil has a harmful effect on several bacteria, pointing to an antimicrobial property. In fact, it had an inhibitory impact on *Escherichia coli* and *Staphylococcus aureus* (Baydar et al., 2006; Rotava et al., 2009). Resveratrol, like other phenolic compounds, exhibits antibacterial activity by causing oxidative damage to bacterial membranes, particularly those of *E. coli*, without harming the host cells. These results imply that resveratrol administration would support conventional treatments when antibiotics are ineffective (Subramanian et al., 2014).

Other grape products, such as grape juice, wine, seeds, and seed extract, could be utilized as dietary supplements for their antioxidant characteristics even if the procedure of extracting the oil from grape seeds may diminish its antioxidant capacity to 50% (Xia et al., 2010). Grape seed extract contains phenolic chemicals that not only have antioxidant activity but also antibacterial, anticancer, cardioprotective, and antiaging properties. These findings have been applied to clinical and preclinical investigations that explore the possible therapeutic use of grape seed oil. These results were mostly based on *in vitro* studies, in which various cells are incubated with grape seed oil and examined for distinct features.

Antitumor activities

Previous research has indicated that the natural polyphenols in grape seeds have promised anticancer action (Zhao et al., 1999; Zhu et al., 2015). In studies using cell culture and animal models, these substances were discovered to interfere with gene expression or signaling pathways, influencing intracellular processes in harmed and healthy cells (Huang et al., 2012; Cheah et al., 2014; Li et al., 2014). Grape seed tocotrienols have also been discovered to have anticancer properties (Choi and Lee, 2009). Current anticancer research has considered supplementing plant phytosterols (Fakih et al., 2018; Sánchez-Crisóstomo et al., 2019; Hutchinson et al., 2019). To increase the therapeutic effectiveness of anticancer medications and lessen their toxicity in clinical applications, GSO has been employed as the foundation of lipid nano-carriers (Lacatusu et al., 2015). In general, some of the phenolic components in grape seed oil such as tocotrienols, proanthocyanidins, and phytosterols are

cytotoxic to tumor cells without harming healthy cells and have anticancer properties.

Cardioprotective activities

The potential of GSO to protect the heart has been investigated in several researches. Platelet adhesion has diminished in *in vitro* research (Garavaglia et al., 2016). Animal research has investigated its impact on lipid levels and rat cholesterol (Asadi et al., 2010; Shinagawa et al., 2017). Grape seed oil's polyphenols and phytosterols have been proposed as natural nutraceuticals to enhance treatments for cardiovascular diseases (Scognamiglio et al., 2019). More study is necessary, nevertheless, to determine how GSO affects the lipid profiles of people (Garavaglia et al., 2016). In animal studies, linoleic acid, prevalent in GSO, has also demonstrated the ability to improve cardiovascular health, indicating promise as a nutritional supplement (Kolar et al., 2019). Collectively, because of the presence of abundant significant antioxidants such as vitamin E and omega-6 fatty acids in grapeseed oil, it could be considered as heart-healthy oil which decreases risk of heart disease.

Dietary supplementation of GSO

The GSO additives in chicken diets have demonstrated encouraging outcomes in lowering cholesterol and fat content (Bialek et al., 2017). Moreover, studies on the benefits of adding GSO to the diets of animals raised for human utilization have shown improvements in antioxidant status and lipid profiles in ruminant animals and lower fat levels in pig meat (Sharifi et al., 2017; Shinagawa et al., 2017).

Vegetable oils, including GSO, are an alternative to animal fats for human utilization and have also been demonstrated to have cardio-protective qualities. To treat hyperlipidemic postprandial situations, grape seed extracts have been combined with oil supplementation (Fernández-Iglesias et al., 2014). As a source of other fatty acids, linoleic acid (LIA), an important fatty acid that the human body cannot produce, must be supplemented in the diet. To minimize inflammatory processes, the diet's omega-6/omega-3 fatty acid ratios should be carefully studied; a ratio of 4–5/1 is advised (Raphael and Sordillo, 2013).

According to Matthäus (2008) and Shinagawa et al. (2015 b, 2017), oxidative stress caused by the degradation of lipid chains has been linked to chronic diseases. There is proof that GSO's fatty acids may include pro-oxidative elements (de Catalfo et al., 2008, 2009). Nevertheless, animal studies comparing different oils have not produced firm conclusions, and further research is needed to determine the precise bioactivity and doses of LIA that are recommended to be taken in by humans (Orsavova et al., 2015).

Useful impacts of GSO on livestock health and production

Growth performance

It has been demonstrated that providing grape pomace to animal food has several advantages for the health

of the animals and the final product's quality (Figure 4). Up to 20% of grape pomace was supplied to the diet of rabbit buck males, and this boosted antioxidant properties without influencing body weight gain or semen quality or quantity (Eid, 2008). The impact of grape pomace on the meat's quality when produced by rearing rabbits is still being determined. The grape pomace is anticipated to be added to diets at about 20% without affecting animal productivity. Still, it may lengthen the meat's shelf-life if phenolic chemicals from the by-products are transmitted to the flesh. Several species have demonstrated encouraging outcomes, including the prevention of harmful bacteria in pigs, the decrease of methane in dairy cows, the rise in polyunsaturated fatty acids, and a decrease in oxidation in the flesh of chicks, pigs, and lambs.

Research on chickens has revealed that adding GSO to their meals may enhance their ability to develop. The GSO enhanced mean body mass and improved the nutritional conversion rate in broilers (Tekeli et al., 2014; Bander, 2017). Nevertheless, no noticeable impacts were noted when 2.5% GSO was added to meals over the entire trial period (Vlaicu et al., 2017). Also, the GSO supplements to broiler's nutrition exhibited no discernible impact on growth metrics, slaughter yield, or organ yields. In contrast, carcass and organ production were superior in the GSO-fed birds than in the control ones (Turcu et al., 2021).

However, a study on rabbits revealed that the supplements of grape pomace to their diets improved the fat % and altered the fatty acid levels of the *longissimus dorsi*

muscle. In contrast, the feed conversion level was greater, while the carcass mass and yield were relatively low compared to the control diet (Bouzaida et al., 2021). Yet, equivalent weight increases were seen in rabbit bucks given either a base diet or a diet that included 10% or 20% pomace as an addition to the diet (Eid, 2008).

Hassan et al. (2016) stated that rabbits which received 300 mg of grape seed extract (GSE) per kilogram of chow at 10 and 14 weeks of age had considerably larger body weights. However, the rise in body mass in the groups that received 100 and 200 GSE was not noteworthy. Regarding the increase in body weight during the experiment, the 200 GSE group came in second to the 300 GSE group. The feed conversion rate of the 100, 200, and 300 GSE treatments did not substantially increase compared to the control ones (by 1.03%, 2.19%, and 3.58%, respectively). The 300 GSE group's feed conversion rate was considerably enhanced compared to the other groups. According to Liu et al. (2011), adding tannins from chestnut extraction to rabbit feed boosted daily growth. The weight growth of NZW rabbits given 0.1%, 0.2% GSE, and 0.1%, 0.2% grape peel extract, according to Choi et al. (2010), was not substantially changed. Moreover, Hassan et al. (2014) discovered that under demanding summer conditions, rabbits getting 1.0% grape seed powder (GSP) in their diet have the largest ultimate body masses (2436 g) and greater daily weight increases (29.9 g/rabbit), followed by those getting 0.5%, 1.5% GSP, and the control condition.

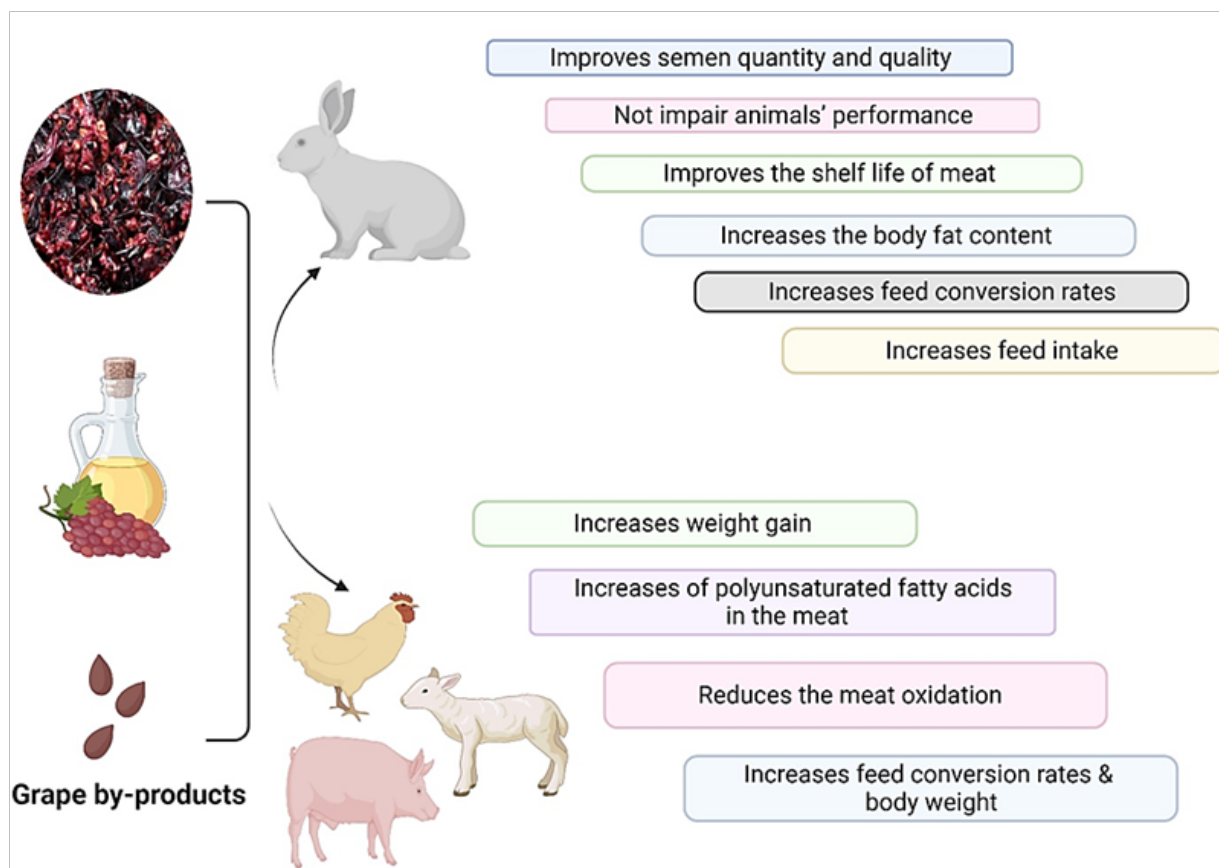


Figure 4. Effect of GSO on growth performance of some animal species

Earlier researches (Goñi et al., 2007; Chamorro et al., 2015; Brenes et al., 2008) have demonstrated that the nutritional treatment of grape pomace boosts the antioxidant capability of broiler food, excreta, and meat. According to Nardoia's (2016) research, the grape skin group's daily weight increase and feed conversion ratio were considerably lower than the birds given other treatments. The grape seed extracted meal acts as a natural antioxidant which plays a crucial role in delaying lipid oxidation in eggs without undesirable effects on hens productivity because of its high content of polyunsaturated fatty acid (Vlaicu et al., 2021). On the other hand, dietary interventions had no impact on feed consumption. When varying levels of seeds, skins, and pomace were added to broiler diets, there was no effect on the hens' performance. However, adding fermented and unfermented skin diets and higher levels of grape skin decreased the productivity of the hens, negatively impacting their feed conversion rate and daily weight growth. The vitamin E administration had no impact on the performance metrics of hens (Nardoia, 2016).

Ozgan et al. (2009) discovered that 2% GSO-containing meals had no significant impact on standard daily weight gain. Tekeli et al. (2014) discovered that adding 15 g/kg of GSO into broiler diets for 1–42 days increased the daily average body weight and feed conversion ratio in Ross 308 broilers. Also, the quail's diets enriched with grape seed showed improved development performance. They had less weight, better feed utilization, quicker growth rate, and greater protein consumption than those in the control group between 10 and 38 days (Abdel-Wahab et al., 2018). Dietary therapy substantially affected the growth characteristics measured at 38 days, with the biggest benefits reported in quails fed diets enriched with 3% grape seed, followed by 1% grape seed (Abdel-Wahab et al., 2018). In general, dietary inclusion of different levels of grape seeds, skins, or pomace ranging from 100 mg to 20 g/kg diet in broiler, rabbits, and other livestock could improve growth performance, weight gain, and enhance feed conversion ratio.

Carcass traits

Regarding carcass features, Hassan et al. (2016) discovered that supplements with grape seed extract (GSE) enhanced the carcass weight for groups 100 GSE and 200 GSE considerably but did not affect the pre-slaughter body weight of rabbits. For every dietary GSE amount, the dressing % was substantially higher in the treatments than in the control group (Figure 5). At rising GSE levels, the proportion of all edible components increased, whereas the percentage of all inedible sections declined. The hair percentage, kidney, head, heart, renal fat, liver, cecum, spleen, and lung were unaffected by GSE concentrations. In addition, including GSE in the meals considerably lengthened the intestines. The findings show that adding GSE to the diet may enhance the carcass characteristics of rabbits under oxidative stress (Dogan and Celik, 2012). In fact, Hassan et al. (2016)

discovered a substantial rise in carcass weights of 10.9%, 9.47%, and 7.1% in groups 100, 200, and 300 GSE, respectively.

Similarly, Hajati et al. (2015) stated that GSE feeding revealed no significant impact on the carcass qualities or the comparative lengths of the intestinal tract and ceca during heat stress. Brenes et al. (2008) discovered that broiler hens consuming GSE at 0.6, 1.8, and 3.6 g/kg diet observed a substantial decrease in the relative length of the jejunum and the ileum. Physical measures taken after slaughter exhibited no significant variances among the three sets of broilers for the breast and thigh weights, but the liver weights were considerably greater in the group treated with GSO (Vlaicu et al., 2017). This is in line with the findings of Amer et al. (2014) who observed that dietary GSE supplements of 1.0% raised only carcass and pre-slaughter weights. According to Brenes et al. (2008), the relative organ weights were unaffected by adding grape seed extract at grading dosages of 0.6, 1.8, and 3.6 g/kg (pancreas, spleen, liver). Collectively, dietary inclusion of different levels of grape seeds, skins, or pomace ranging from 100 mg to 20 g/kg diet in rabbits could enhance the carcass weight, edible parts proportion, intestines length, and liver weight.

Blood parameters

In rabbits, Hassan et al. (2016) discovered that groups 200 and 300 GSE had substantially greater plasma total protein, globulin, and albumin concentrations than the 100 GSE group and such in the control group. Serum glucose levels and the albumin/globulin proportion did not substantially vary across the experimental groups. Nevertheless, when the dietary amounts of GSE increased, blood total lipids, cholesterol, and triglyceride dramatically decreased. The serum HDL level was reduced statistically following GSE intake, although this impact was not significant. However, once dietary GSE levels rose, the percentage of LDL dropped considerably in contrast. In prior research, Amer et al. (2014) found that rabbits fed a 1.5% GSP diet had plasma total protein and globulin levels that were considerably greater than those given a 0.5% and 1.0% GSP diet. At high dietary quantities of GSE, blood glucose levels in the current research dropped. The significant binding potential of GSE towards glycodeoxycholic acid might have been the cause of the loss of total cholesterol, which led to a rise in fecal bile acid secretion and a reduction in blood cholesterol (Adisakwattana et al., 2010). In addition, Mansouri et al. (2015) discovered that grape seed proanthocyanidin extract considerably lowered LDL levels and decreased total lipid levels, whereas HDL levels were not significantly impacted. Collectively, dietary inclusion of different levels of grape seeds ranging from 200 mg to 20 g/kg diet in rabbits increased the concentrations of plasma total protein, globulin, and albumin and reduced total lipids, cholesterol, LDL, and triglyceride.

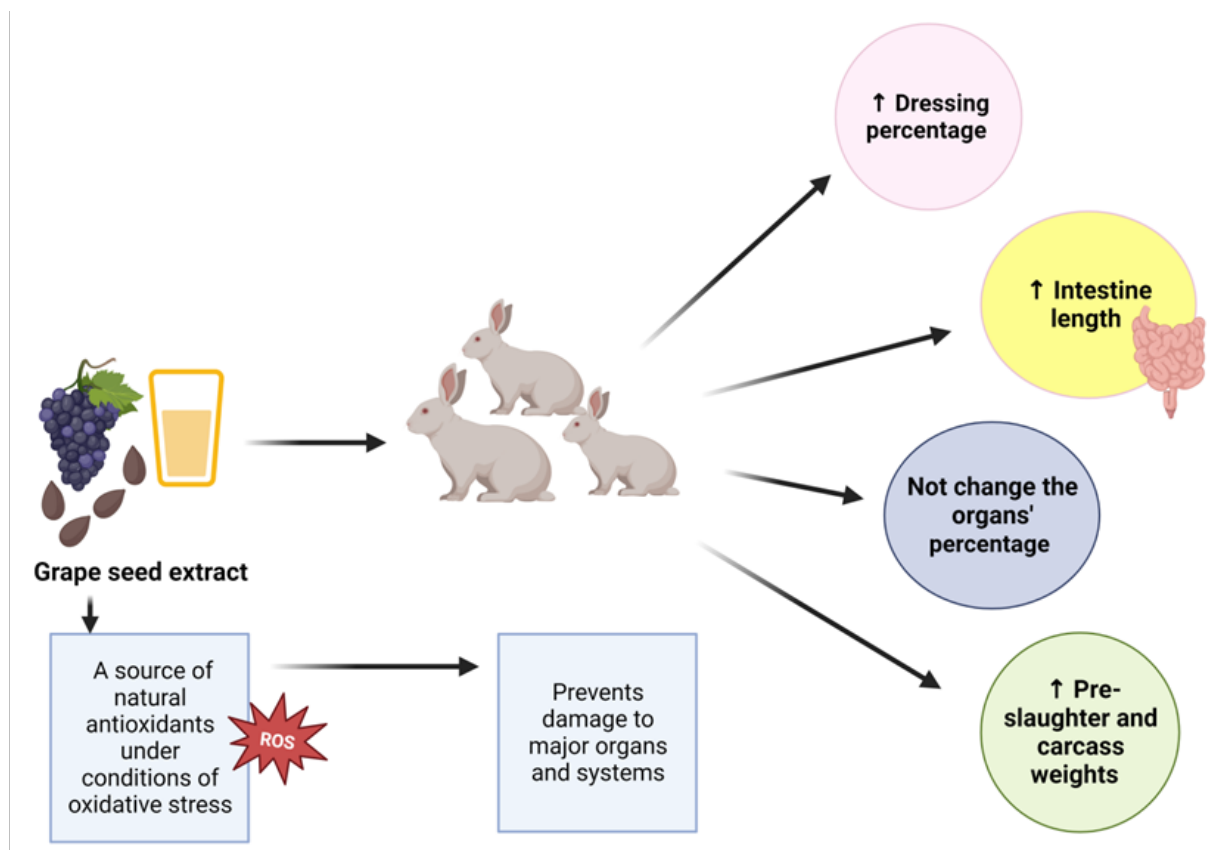


Figure 5. Effect of GSO on rabbit carcass traits

Antioxidative status

To maximize the antioxidant activities of diets and meat to maintain quality, antioxidants must be added to feed (Goñi et al., 2007). Yet, because synthetic antioxidants have been used for so long, people are now more worried about consuming hazardous items. To address this, natural antioxidants with significant biochemical activity in minimizing the consequences of metabolic disorders have been found to be an alternative to synthetic ones (Yan and Kim, 2011; Bennato et al., 2020). By preventing rancidity from occurring and extending meat's shelf life, natural antioxidants promote food security and safety (Turcu et al., 2021).

Adding GSO to the diet significantly increased the meat's capacity to resist oxidation. Compared to the 0% GSO group, the 1.5% GSO and 3% GSO groups dramatically increased their concentrations of conjugated trienes and dienes after seven days of chilling (Turcu et al., 2021). In contrast to 0% GSO, 3% GSO exhibited the least TBARS, while the 1.5% GSO group also had a much lower value of p-anisidine. Lipid oxidation is one of the primary methods through which the integrity of meat and meat-related products degrade (Smet et al., 2008).

The capacity of cells' inherent antioxidants to destroy various oxidizing chemical species and their creation, which causes oxidative stress, is out of balance (Scandalios, 2005). Broiler meat that included 1% GSO had much

lower malonaldehyde and peroxide index readings, indicating that the meat's oxidative condition had improved (Salman, 2019). Bander (2017) observed similar outcomes with a level of 1% GSO. On the contrary, Mancini et al. (2018) and North et al. (2019) found no variation in the antioxidant activities of the rabbits' meat that were fed supplemented diets with substances high in polyphenolic compounds (4 or 8 g of ginger powder in 100 g of feed or with 2 g of quercetin/kg diet, respectively).

According to Perna et al. (2019), the meat of rabbits fed meals with goji berries or cauliflower had higher overall phenolic levels and antioxidant activities than the control groups (Menchetti et al., 2020). Goñi et al. (2007) demonstrated that broilers' meat antioxidant properties increased when grape pomace was added to their diet at up to 30 g/kg. Zhao et al. (2018) showed that ram lambs given diet supplemented with wine grape pomace (at levels of 0%, 5%, and 10%) boosted their overall antioxidant potential, glutathione peroxidase 4, and superoxide dismutase activities. The antioxidant potential of chicken breast and thigh patties was increased when grape pomace and skin were added to the diet of the chicken up to 40 g/kg and when grape seed and skin were added directly at a rate of 20 g/kg, respectively. These findings demonstrate the anti-lipid oxidation properties of dietary grape pomace or skin (Nardoia, 2016) (Figure 6). Collectively, dietary inclusion of different levels of grape seeds, pomace and skin ranging from 100 mg to 30 g/kg diet in

broiler and rabbits increased the meat's capacity to resist oxidation and lower TBARS as well as malonaldehyde and peroxide index readings.

Gut microbiota

GSO's medicinal properties, including its antioxidant, antibacterial, and antifungal properties, have been addressed (Dabetic et al., 2020). Because it contains a significant amount of unsaturated fats, these characteristics enable GSO to lower cholesterol levels, enhance oxidative stress and lipid profiles, prevent the growth of certain pathogens, including *E. coli* and *Staphylococcus aureus*, and have a cardio-protective impact. The use of GSO in broilers has been supported by research by Tekeli et al. (2014), Banaszkiewicz et al. (2018), and Salman (2019), which has demonstrated beneficial impacts on plasma parameters, production efficiency, oxidative stability, and fatty acids of meat. The supplementation of unfermented and/or fermented meals to chicken ileal contents did not significantly affect the bacterial growth of *Clostridium* and *Lactobacillus* (anaerobic) and *E. coli* (aerobic) (Nardoia, 2016).

The microbiome in the digestive tract may change intestinal microorganisms' composition and/or activities by metabolizing polyphenols into more bioactive chemicals with various physiological implications (Bustos et al., 2012). Consequently, dietary polyphenols may affect the gut microbe's population through two-way phenolic-microbiota interactions. By inhibiting or promoting the growth of gut microbial constituents, unabsorbed dietary phenolics may have a major impact on the gut tract. Flavonoids found in grape by-products have been demonstrated *in vitro* to restrain the development of bacteria like *E. coli*, *S. aureus*, *Candida albicans*, and *Campylobacter* sp. (Papadopoulou et al., 2005; Ozkan et al., 2004; Vaquero et al., 2007; Gañan et al., 2009; Silván et al., 2013). Moreover, polyphenols and their metabolites have an impact on the ecosystem of the intestines since a sizeable fraction of them are not completely absorbed, rather they undergo liver metabolism, are secreted through the bile in the form of glucuronides, and are deposited in the lumen of the ileum and colon (Tzounis et al., 2007) (Figure 7).

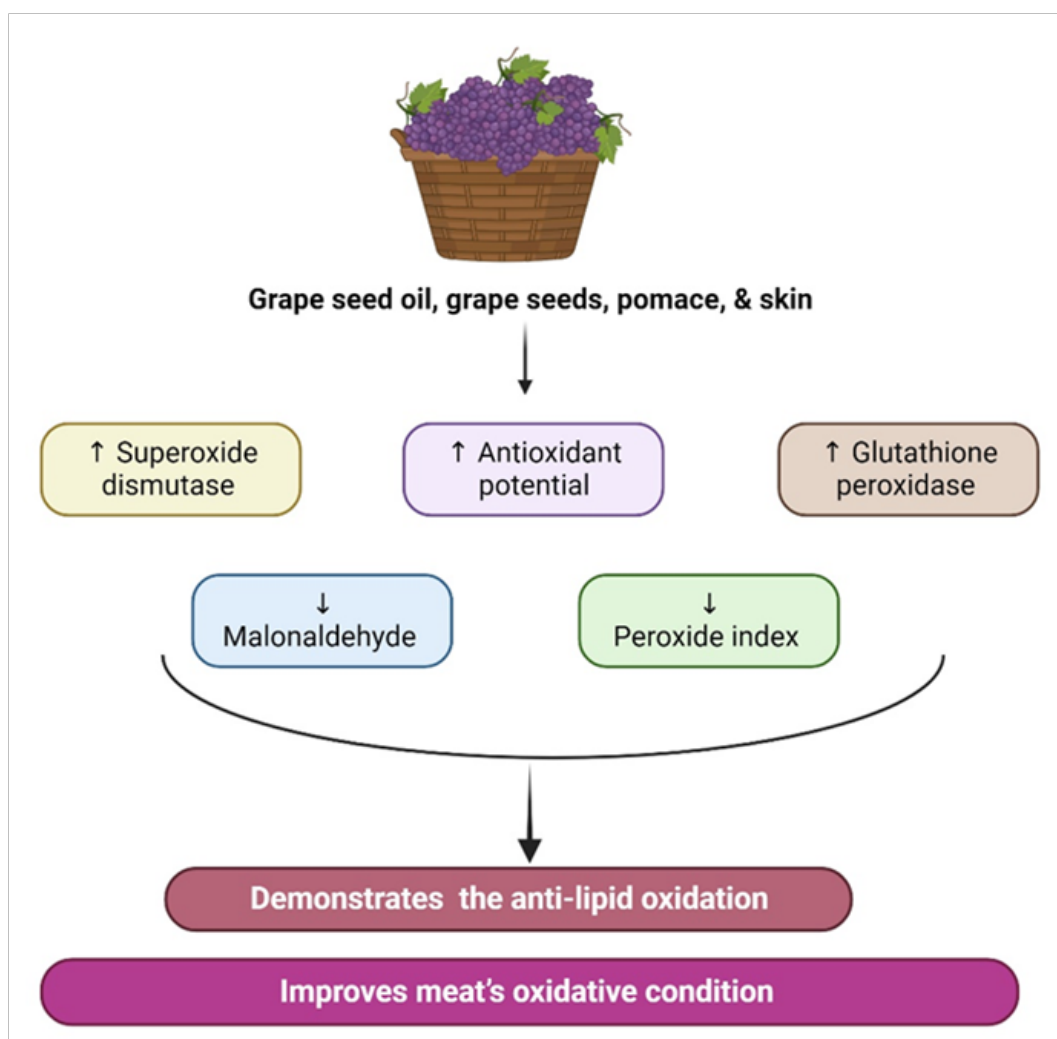


Figure 6. The antioxidant activity of grape by-products

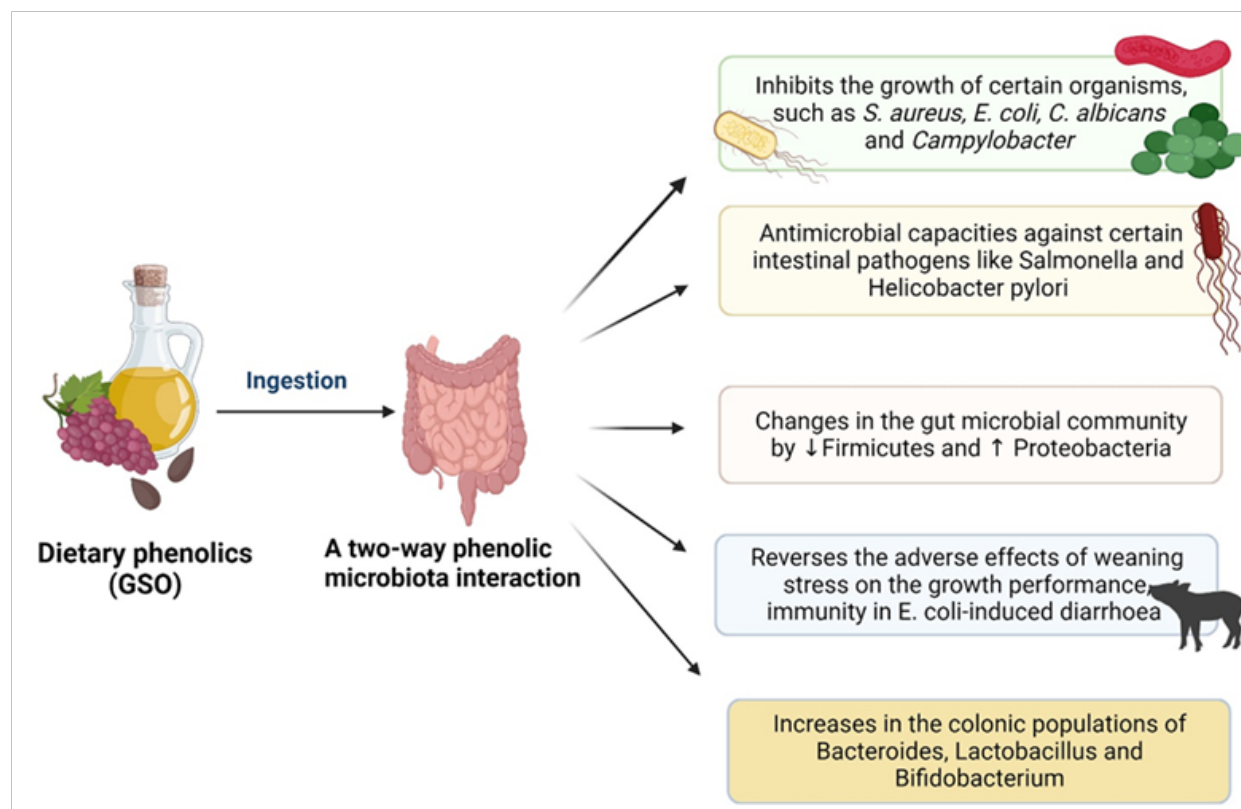


Figure 7. The effect of grape seed by-products on the gut's microbiota

Several polyphenolic substances, including phenolic acids, resveratrol, quercetin, and hydroxytyrosol, revealed an antibacterial effect helpful for gut infections including *Helicobacter pylori* and *Salmonella* sp. (Daroach et al., 2001; Just and Daeschel, 2003). Grape polyphenols have been associated with suppressing the development of a wide range of pathogens, with polymeric flavonoids (procyanidins) being more active than monomeric flavonoids (Mayer et al., 2008). The biotransformation of nutritional phenolic composites by microbes, including phenolic acids, has been found to alter intestinal bacterial strains selectively, potentially influencing gut microorganisms' variability and metabolic functions (Cueva et al., 2010). Unfortunately, only a few strains of bacteria that may break down dietary polyphenols have been found, notably *Flavonifracter plautii* and *Eubacterium ramulus* (Braune et al., 2001; Schoefer et al., 2002).

Grape polyphenols may alter the microbial ecology within the gut by increasing proteobacteria and suppressing the firmicutes (Kemperman et al., 2013). *In vivo* research has shown that resveratrol may be used instead of antibiotics to reverse the negative consequences of weaning stress on growing parameters, immunology, and the bacterial ecology in pigs challenged with *Salmonella* sp. and *E. coli* (Ahmed et al., 2013). Grape seed extract (GSE) has been shown to prevent *E. coli*-induced diarrhea in young pigs (Verhelst et al., 2014). GSE and grape

marc meal extract were observed to change the bacterial communities, with a decrease in *Clostridium* sp. and *Streptococcus* sp. within the intestinal microbiome (Fiesel et al., 2014). Other researchers found no alterations in the microbial population in the cecum and feces of piglets given a polyphenol extract-containing GSE (Zhang et al., 2014).

Bacteroides, *Lactobacillus*, and *Bifidobacterium* colonic populations have been found to grow in rats whose diets contain grape seed polyphenols (Dolara et al., 2005; Larrosa et al., 2009; Pozuelo et al., 2012). *Lachnospiraceae*, *Ruminococcaceae*, *Clostridiales*, and *Lactobacillus* have significantly increased in the microbiome of female pigs given a 1% GSE meal, indicating an ecological change (Choy et al., 2014).

Research on birds has also shown that polyphenols have antimicrobial and prebiotic properties (El-Sabrou et al., 2023; Iqbal et al., 2020). According to a study, feeding grape by-products to birds reduces *Clostridium* numbers in the ileum and boosts *Lactobacillus* and *Enterococcus* populations in the cecum (Viveros et al., 2011). The potential prebiotic impact of these by-products has been proven by molecular methods (TRFLP), which have shown a rise in biodiversity and the identification of specific microorganisms with the ability to break down phenols along with other unknown species in the cecum of birds that feed on all these by-products.

Meat quality

Meat quality is a crucial aspect when it comes to fulfilling consumers' demands and expectations in terms of safety, health benefits, and personal beliefs (Biswas and Mandal, 2020; Šrédl et al., 2021). Consumer preferences in purchasing meat products are impacted by various variables, such as medical conditions, genetic predispositions, cultural traditions, and social evolution (Aschemann-Witzel et al., 2019). The most popular form of meat is broiler since it is inexpensive and produced sustainably (Pinto da Rosa et al., 2021).

Developing new strategies to increase the nutrient quality of animal products is essential. Natural ingredients are often used in the formulation of poultry diets to provide particular minerals that are good for human health to animal products (Attia et al., 2018; Fan et al., 2020). One effective method of nutrient enrichment is through polyunsaturated fatty acids (PUFA), specifically, omega-3 (n-3) and omega-6 (n-6), which are necessary for healthy physiological processes but cannot be synthesized by humans and animals (Banaszkiewicz et al., 2018). Adding vegetable oils to broilers feed is a useful tactic for elevating the number of fatty acids in the meat of chicken (Oomah, 2019). In addition to being useful for animal feed, the recovery of flaxseed meal, a by-product of flaxseed oil extraction, helps to ensure the long-term viability of the flaxseed industry (Lan et al., 2020).

Flaxseed meal is important for enriching meat with PUFA n-3 in broiler diets. Still, its inclusion is limited due to the susceptibility of PUFA enrichment to lipid peroxidation, which decreases broiler meat's flavor, texture, consistency, color, and nutritional value. Antioxidant supplementation in meals is therefore required. According to Turcu et al. (2021), the addition of GSO to broiler diets affected the lightness and pH of thigh meat samples, with the 3% GSO group exhibiting noticeably lower pH values and greater lightness values than the control group. Moreover, when added to broiler diets, GSO increased the amount of saturated fatty acids (SFA) and decreased the amount of PUFA, especially PUFA omega-6 and omega-3, in the 1.5% GSO group compared to the control group. The PUFA n-3 concentration was significantly lower, and the omega-6/omega-3 fatty acid proportion was higher in the 3% GSO subgroup. Compared to the control subgroup, the 3% GSO group's breast meat had a significantly higher SFA content and a better PUFA omega-6/omega-3 fatty acid level. Regarding thigh meat's health lipids indicators, the 3% GSO group's atherogenicity index dropped, while the 1.5% GSO group's thrombogenicity index rose compared to the control group. Compared to the control group, the hypo- and hypercholesterolemic ratio in the boneless skinless thighs of the 1.5% GSO group was considerably lower.

The color of the meat is a crucial sign of the product's freshness and quality. Many factors affect the color of a chicken's flesh, including genetics, food, the makeup of muscle fibers, and heme pigments. Moreover, the color and fragrance of meat are both impacted by PUFA levels.

According to Nardoia (2016), birds given α -tocopherol, grape seed (40 g/kg), grape pomace (40 g/kg), and skin (40, 110 g/kg) had higher plasma and flesh α -tocopherol concentrations. As opposed to birds given the various grape by-products, those getting α -tocopherol diets experienced this impact more strongly.

Egg quality

Hen eggs have a great nutritional value because of their diverse components, which includes high concentration of vital amino acids, low calorie count, abundance in vitamins A, E, B₇, and B₁₂, and high content of zinc, iron, and phosphorus (Herron and Fernandez, 2004; Nau et al., 2010; López-Sobaler et al., 2017). Moreover, due to their abundance in bioactive substances with nutraceutical qualities including phospholipids, ovalbumin, ovotransferrin, selenium, and choline (Anton et al., 2006; Zdrojewicz et al., 2016), eggs might be considered functional foods. Therefore, it has been demonstrated that moderate egg consumption has positive effects on human health, such as the reduction of hypertension, the prevention of aging, and the improvement of ocular health (Nimalaratne et al., 2011; Liu et al., 2014; Aparicio et al., 2018).

Increasing the amount of polyunsaturated fatty acids (PUFA) in eggs can further improve the nutritional value of hen's eggs. PUFA consumption has been linked to improved cognitive function (Jiao et al., 2014) and a decreased risk of cardiovascular disorders (Juturu, 2008). By providing sources of PUFA in laying hens' diets, such as linseed oil or cod liver oil, it is possible to enrich hen eggs with these fats (Lewis et al., 2000; Lemahieu et al., 2015). Moreover, reducing egg lipid peroxidation could be achieved by feeding laying hens antioxidant supplements like α -tocopheryl acetate (Grune et al., 2001). However, to improve the stability of egg lipids, other substances with antioxidant capabilities, such as polyphenols, could potentially be added to hens' diets (Vastolo et al., 2022). In fact, it has been demonstrated that phenolic compounds from grapes, primarily catechins and proanthocyanidins, have the ability to scavenge free radicals and stop oxidative processes (Yilmaz and Toledo, 2006). In this regard, a number of studies (Aditya et al., 2018; Nardoia et al., 2020; Romero et al., 2021 a, b) reported that the dietary inclusion of grape by-products (grape pomace, grape seeds, and grape skins) was successful in reducing lipid oxidation in the meat of broiler chickens. However, there are few studies evaluating the impact of the dietary inclusion of grape by-products.

While feeding laying hens diets rich in grape polyphenol sources did not affect the thickness of their shells, it did improve the color of their yolks and the number of Haugh units in their albumen. The dietary inclusion of grape pomace in laying hens (Kara et al., 2016) or quails (Frões et al., 2018) or that of grape seeds in these same species (Kaya et al., 2014; Silici et al., 2011) was also reported to have no effect on egg shell thickness.

Little information is available about the effect of feeding grape products on yolk color and Haugh units in laying hens. While Kara et al. (2016) found no significant effect of feeding up to 60 g/kg of GP on egg yolk colour in laying hens, Fróes et al. (2018) found a positive quadratic relationship between yolk pigmentation and grape pomace dietary level in quails. Grapes, as well as tomato and red pepper, are natural sources of β -carotene and lutein (Bunea et al., 2012), which are pigmenting substances commonly used in European feed mills to achieve the optimal yolk coloration desired by customers (Galobart et al., 2004). Thus, the inclusion of grape products in the diet of laying hens could contribute to somewhat reducing the dietary use of synthetic pigments (Castellanos-Gallo et al., 2022).

Concerning the effect of the dietary inclusion of grape products on Haugh units, no consistent results seem to have been obtained among the few research studies available on this topic. On the one hand, Kara et al. (2016) and Fróes et al. (2018) found that the Haugh units of the albumen remained unaffected despite the inclusion of grape pomace in the diet of laying hens or quails, respectively, but on the other hand, Haugh units increased linearly with increasing dietary doses of grape seeds and grape seed extract in the work of Kaya et al. (2014). Therefore, further research is likely to be needed to confirm the effect produced on Haugh units by the dietary use of grape products.

Histological observations

In broilers, Nardoia (2016) found that applying various amounts of grape seed and skin to birds' diets significantly enhanced the total polyphenol levels in the ileum and excrement. All treatment groups, except those given grape pomace, had higher ileal tannin levels, but there was no difference in excreta tannin levels. The protein content was unaffected. However, lower levels were found in chickens given skin (110 g/kg) and unfermented skin (60 g/kg). Feeding chickens with pomace, seed, and skin led to a rise in ileal phenolic contents. Nevertheless, birds that have been given fermented and unfermented skin, seed, and mixtures of both grape seed and skin diets did not exhibit any differences in the ileal solubility of phenolic content. Also, adding different amounts of seed, skin, and pomace did not affect the excreta's ability to absorb polyphenols. Nevertheless, there was an increase in hens given both unfermented and fermented skin, with the greatest results for unfermented skin, seed, skin, and pomace, respectively, and the mixtures of skin and seed diets.

In a subsequent rabbit investigation by Hassan and AL-Ghaban (2019), GSO was discovered to be a bioactive phenolic compound that helps to speed up the bone's recovery following tooth extractions. After two weeks, histological analysis revealed that seed oil encouraged much more osteoblasts, osteoclasts, and osteocytes than the sponges and control sample, particularly in the apical region of the socket. A very significant variation in

the overall markers of bone microarchitectures, such as trabecular area, trabecular frequency, and bone marrow space area, was seen in all groups' histological characteristics.

Conclusion

In conclusion, the presence of abundant antioxidants such as vitamin E, phenolic compounds and omega-6 fatty acids in grapeseed oil led it to be a strong antioxidant that helped the body repair from free radical-damages and decreased the risk of heart disease. In addition, the phenolic components present in grape seed oil such as tocotrienols, proanthocyanidins, and phytosterols could inhibit the release of AA, NO, and other cytokines, which is necessary for the inflammatory response, so it might be considered as a potent antiinflammatory agent in addition to their antitumor activity due to their cytotoxic effects against tumor cells rather than healthy cells. Dietary inclusion of different levels of grape seeds, pomace and skin ranging from 100 mg to 30 g/kg diet particularly in broilers and rabbits improved the growth performance, weight gain, and enhanced feed conversion ratio. It also increased the meat's capacity to resist oxidation and lower TBARS as well as malonaldehyde and peroxide index readings. Moreover, it increased the concentrations of plasma total protein, globulin, and albumin and reduced total lipids, cholesterol, LDL, and triglyceride. Also, it could enhance the carcass weight, edible parts proportion, intestines length, and liver weight. Grape seed extract improved carcass traits under oxidative stress conditions. These benefits make it a promising natural alternative to synthetic antioxidants in animal feed. However, more researches are still required to determine the optimal doses and potential side effects of grape seed oil and its components for human consumption.

Conflicts of interest

All authors declare that they have no conflicts of interest that could inappropriately influence this manuscript.

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Author contribution

All authors contributed equally to writing this review article. All authors read and approved the final version of this manuscript.

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