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Application of natural antioxidants as feed additives to improve animal health and enhance food quality in livestock farming

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ABSTRACT

Feed additives are used in animal nutrition for a variety of reasons, including improving feed quality, regulating rumen fermentation, increasing product quality and yield, and improving animal health. Antioxidant substances constitute an important group among feed additives. The oxidation process degrades lipids in feed components, reducing their nutritional value. Consequently, animal health suffers, and productivity decreases. As a result, animal health is negatively affected and yield decreases. Adding antioxidant additives to feeds and especially to rations with high fat content is an effective method to overcome these problems. Antioxidants used in animal nutrition can be natural or synthetic substances. Of these, those with natural content are in demand and the effects of these substances are frequently investigated. Research conducted every day reveals the benefits of these substances to animal health. Natural antioxidant substances such as vitamins, minerals, carotenoids, flavonoids and polyphenols are frequently used in farm animal husbandry. In this review, the properties of natural antioxidant feed additives used in livestock farming are specified and their positive effects on animal health and food quality are emphasized.

Keywords: Animal nutrition, oxidative stress, oxidation

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Introduction

Oxygen is essential for living organisms. However, when unsaturated fatty acids are exposed to oxygen, they undergo adverse changes in their molecular structures. Free radicals are created when a double bond in an unsaturated fatty acid breaks and interacts with oxygen. Free radicals damage proteins, nucleic acids, and DNA, the building blocks of cells, causing diseases like cancer and diabetes. Free radical-induced oxidative stress harms organisms and cells in their regular functions. However, cells do not undergo auto-oxidation because antioxidants, such as vitamins C and E, inhibit this process (Bayraktar, 2003; Bingöl 1981; Yesilbağ, 2009; Çaylak, 2011; Velioğlu, 2000).

The peroxidation of lipids is a chain reaction. In the first stage of fatty acid oxidation, hydroperoxides are formed. Hydroperoxides have no taste or smell. Glutathione peroxidase oversees the elimination of hydroperoxides produced inside the cells. Glutathione peroxidase prevents lipid peroxidation from damaging the cell structure. When hydroperoxides break down, they decompose into peroxides and odorous compounds such as aldehydes, ketones, and hydrocarbons. Malonaldehydes are compounds that emerge during the process of lipid peroxidation. Even small amounts of these compounds cause significant changes in the taste and smell of the lipids. When peroxides begin to form, their powerful catalytic effects cause the lipid to oxidize rapidly on its own (Bayraktar,

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2003; Bingöl, 1981; Atalay, 2011; Tsai, 1975; Pamukçu et al., 2001; İmik et al., 2009).

Antioxidants are substances that inhibit the production of free radicals and stop lipids from oxidizing (Çelik and Ayran, 2020). Naturally existing enzymatic and non-enzymatic antioxidant mechanisms are available to neutralize free radicals produced during oxidation within organisms. These antioxidants work through a variety of mechanisms, including breaking the oxidative chain that generates free radicals (α-tocopherol), reducing glutathione directly in the environment, neutralizing the first free radical to form (superoxide dismutase) and binding metals (ceruloplasmin) (Yeşilbağ, 2009; Çaylak 2011).

Superoxide dismutase (SOD), one of the natural antioxidant enzymes, is an essential enzyme found in every cell. It exists in various forms and prevents the formation of free radicals. Glutathione peroxidase is a selenium-containing enzyme found in the mitochondria and cytoplasm. It reduces H2O2 to H2O. Catalase (CAT) is found in animal organisms and is often found in peroxisomes of cells. CAT reduces hydrogen peroxide to water. H2O2 that passes from the mitochondria to the cytosol is detoxified by CAT. CAT can clear H2O2 more effectively than glutathione peroxidase. Glutathione reductase (GR) is an enzyme that contains flavin adenine dinucleotide (FAD). Furthermore, NADPH protects against free radical damage (Aslankoç et al., 2019; Karabulut and Gülay, 2016; He et al., 2017).

Medicinal and aromatic plants contain phenolic chemicals that act as antioxidants by preventing peroxidation chains, scavenging free radicals, and establishing chelation with transition metals (Çelik and Ayran, 2020). Vitamin E (α-tocopherol) is a non-enzymatic, fat-soluble antioxidant found in oils and grains, particularly wheat, corn, soybean, and cottonseed oil. Its function is to prevent the peroxidation of lipids through free radical scavenging and to protect against cell damage. Vitamin E is an effective antioxidant that inhibits lipid oxidation chain (Altıner et al., 2017). Beta-carotene is a compound present in vegetables and fruits that is turned into vitamin A (retinol) in the small intestine, giving plants their yellow, red, and orange colors. Vitamin A helps neutralize oxygen and free radicals in the environment, protecting cell membranes from oxidative damage. Vitamin C (ascorbic acid) is a water-soluble antioxidant found in vegetables and citrus fruits that inhibits oxidation and neutralizes free radicals. Strong free radicals are converted into weaker ones by vitamin C when it is present in adequate amounts (Karabulut and Gülay, 2016; Kasnak and Palamutoğlu, 2015).

Overproduction of free radicals leads to oxidative stress, damaging cells and adversely affecting animal health. Antioxidant substances added to feed minimize oxidative stress, improve animal health, and boost performance (Sies, 1997). Antioxidants in feeds include synthetic chemicals, such as butylated hydroxy anisole (BHA), butylated hydroxy toluene (BHT), and ethoxyquin (EQ), as well as natural substances such as tocopherol (vitamin E) and ascorbic acid. Medicinal and aromatic herbs play an essential role as antioxidant feed additives. The antioxidant activities of aromatic plants are attributed to phenolic compounds in fatty acids (Skerget et al., 2005). Rosemary and sage were found to be the most effective antioxidants (Yeşilbağ, 2009). It has been found that feed additives with antioxidant qualities improve animal immune systems, meat quality, and growth performance. Animal productivity and health benefit from reducing oxidative stress, particularly in stressed animals (Fellenberg and Speisky, 2006; Gopi et al., 2014). Commercial feeds are supplemented with antioxidants to protect against oxidative degradation and lipid peroxidation during feed manufacturing, processing, and storage. Foods and feeds high in polyunsaturated fatty acids (PUFA) are more likely to undergo lipid peroxidation. Therefore, antioxidant applications in animal feeds have increased as PUFA-rich diet compositions have become more common (Decker et al., 2012).

Natural feed additives with antioxidant qualities that are commonly used include vitamins, minerals, carotenoids, flavonoids, and polyphenols. Synthetic antioxidants BHA (Butylated Hydroxy Anisole), BHT (Butylated hydroxytoluene), PG (Propyl Gallate), and TBHQ (Tertiary Butyl Hydroquinone) are also used in feeds to reduce lipid oxidation in addition to natural ingredients. However, concerns about toxicity and residues associated with these substances have led to a growing preference for natural alternatives in recent years (Yeşilbağ, 2009; Çaylak 2011). Medicinal and aromatic plants are among the natural ingredients that are in great demand as feed additives.

This review focuses on natural antioxidant feed additives frequently used in animal nutrition and their positive effects on animal health and food quality are indicated.

Feed additives as antioxidants.

Vitamin E

Vitamin E is a fat-soluble antioxidant that protects cell membranes from oxidative stress. Vitamin E comes in many forms. The most effective form, α-tocopherol, protects lipids in cell membranes from oxidative breakdown. Vitamin E prevents damage by neutralizing free radicals and keeping cell membranes stable. The main antioxidant action of vitamin E is to reduce lipid

peroxidation. Lipid peroxidation occurs when unsaturated fatty acids in cell membranes react with free radicals. This process damages cell membranes and weakens cellular activities. Vitamin E prevents lipid peroxidation by neutralizing free radicals and protecting cell membranes (Burton & Traber, 1990).

Vitamin E is commonly used as a feed additive in animal husbandry, particularly in intensive production in chicken, pig, and cattle farming. Adding vitamin E to feed boosts animal performance while also improving meat and milk quality. Several studies have shown that vitamin E enhances animal immune systems and increases disease resistance (Lee and Han, 2018). High doses of vitamin E were found to prevent oxidative damage in muscle tissues and boost meat quality in broiler chickens (Cheng et al., 2011). It has also been reported that it supports the immune systems of chickens. Vitamin E has a significant role in pig feeding. Adding vitamin E to pig feed lowers lipid peroxidation in muscle tissue and improves meat quality (Mahan, 1994). Vitamin E supplementation in cattle, particularly dairy cows, has been shown to increase milk productivity and quality while also improving reproductive health (Weiss et al., 1997), and it has also been reported to strengthen the immune system and reduce the incidence of mastitis. Vitamin E has also been demonstrated to protect milk quality and delay spoiling due to its antioxidant activity.

In livestock farming, maintaining meat quality is critical for satisfying consumer needs and making a profit. Oxidative stress can degrade the color, flavor, and shelf life of meat. Vitamin E supplementation has been shown to improve meat quality by reducing oxidative stress. Vitamin E has been found to preserve the color of meat and keep it fresher for longer by preventing lipid oxidation (Guerra-Rivas et al., 2016). Moreover, it has been reported that meat from animals given vitamin E supplements has a more flavorful characteristic (Liu et al., 1996).

The use of vitamin E as a feed supplement also benefits the immune systems of animals. Vitamin E has been shown to play an important function in fighting infections and strengthening the immune system. While vitamin E deficiency can cause higher susceptibility to infections in animals, sufficient vitamin E intake boosts the activity of immune cells (Lee and Han, 2008).

As a result, adding vitamin E as a feed addition protects animals against oxidative stress. Vitamin E supplementation in poultry, pig, and cattle husbandry enhances meat and milk quality while also strengthening the immune systems of the animals.

Selenium (Se)

Selenium is present in the structure of glutathione peroxidase, an important antioxidant enzyme. The GPx enzyme shields cell membranes from oxidative damage by inhibiting lipid peroxidation (Aslankoç et al., 2019). Selenium supplementation in animal feed is a widespread practice, particularly in current agricultural practices. The selenium content of food is determined by the soil in which plants or animals are grown or raised. Soils that naturally contain selenium are often limited, resulting in selenium deficiency in plant and animal products. One way to overcome the deficit and promote the overall health of animals is to add selenium to their feed (Surai, 2002). When used in feeds, selenium can typically be found in two forms: inorganic (sodium selenite, sodium selenate) and organic (selenomethionine). Organic selenium sources are said to have a better bioavailability than inorganic selenium (Davis, 2004). Thus, this amplifies its benefits on animal health. Dietary selenium has antioxidant properties. It helps counteract the damaging effects of free radicals (Surai, 2002). Increased oxidative stress is commonly seen in conditions requiring high performance in animals (for example, high milk yield in dairy cows), and selenium protects against this stress (Zheng et al., 2022; Séboussi et al., 2016). Moreover, selenium also benefits animal immune systems. Selenium supplementation can improve immune functions in animals and strengthen their resistance to disease. By encouraging macrophage activity, selenium fortifies the immune system (Arthur et al., 2003). Selenium and vitamin E can work together synergistically to influence biological processes, particularly those involving antioxidants and immunity. Vitamin E and selenium supplementation in animal feed can boost immune response and generate disease resistance (Dalia et al. 2018). Selenium makes animals more resistant to viral and bacterial infections. Selenium supplementation was shown in a study to enhance immunity in broilers by boosting their antioxidant capacity (Qiu et al., 2023). Reproductive health is another benefit of selenium. Insufficient amounts of selenium can lead to problems with reproduction in both female and male animals. According to reports, selenium supplementation raises the likelihood of conception in female animals, lowers the risk of miscarriage, and improves the quality of sperm in male animals (Ahsan et al., 2014). Including selenium in the diet also increases the quality of meats and dairy products. Studies in dairy cows revealed that selenium supplementation increases milk yield and selenium levels in milk (Juniper et al., 2006). Similarly, it also resulted in improvements in meat quality. Selenium prevents lipid oxidation, enhancing meat shelf life and nutritional value (Bai et al., 2022).

When added to feed, selenium is an element that

When added to feed, selenium is an element that significantly improves the productivity and health of animals. Selenium's numerous benefits, including reduced oxidative stress, immune system strength, reproductive health support, and improved meat and milk quality, support its use as a feed addition.

Carotenoids

Carotenoids are naturally occurring pigments found in a wide variety of bacteria, fungus, algae, and plants. More than eight hundred natural carotenoids have been identified in red, orange, yellow, and other colors, and they typically determine the attractive color of fruits. These natural pigments are crucial secondary metabolites that perform a variety of roles throughout a plant's life cycle and exhibit considerable antioxidant activity. These compounds, which animals cannot synthesize, are used in animal nutrition as feed additives, particularly because of their antioxidant properties (Nabi et al., 2020). Carotenoids are a diverse group of compounds, with the most prevalent forms being beta-carotene, lutein, and lycopene. These compounds assist a variety of biological functions, including the antioxidant defense system, immunological system, reproduction, and eye health. Carotenoids are naturally available in feed and, particularly in poultry production, improve egg yolk and skin color while also supporting the immune system (Chew, 1993). Carotenoids serve as powerful antioxidants that protect animal cells from oxidative damage. They neutralize free radicals, inhibit lipid peroxidation, and protect cellular structures (Krinsky and Yeum, 2003).

Carotenoids are widely used in animal nutrition for a variety of animal species, including fish, poultry, and agricultural animals, as feed additives. If natural carotenoids are insufficient, they are added to diets to fulfill the nutritional requirements of animals and support their biological activities (Pasarin and Rovinaru, 2018). Carotenoids in feed additives might be natural or synthetic. While seaweed, red pepper, carrot, and marigold are excellent natural sources, synthetic carotenoids are often chosen due to their stability and regulated dosage. Carotenoids protect cells from oxidative damage caused by free radicals and can lower oxidative stress. To benefit from this characteristic, carotenoids are used as food additives, particularly in stressed animals. Carotenoids protect cell membranes by inhibiting lipid peroxidation and slowing cell aging (Stahl and Sies, 2005). Carotenoids also boost the immune system (Chew & Park, 2004). Carotenoid supplementation benefits animal health by boosting resistance to viral and bacterial infections. A study found that feeds enriched with natural-source carotenoids enhance immune responses in rainbow trout and boost their resistance to diseases (Amar et al., 2004). Furthermore, carotenoids have anti-inflammatory properties in a variety of animal species (Galasso et al., 2018; Moraes et al., 2016). Studies on chickens have shown that carotenoids, including lutein enhance the production of antibodies, offering protection against infections (Koutsos et al., 2003). Astaxanthin is a potent carotenoid that boosts antioxidant levels and the immune system. In fish, it enhances growth and resistance to diseases. Without any cytotoxicity or adverse effects, it is reported to offer disease resistance, growth performance, survival, and enhanced egg quality, particularly in farmed fish. Astaxanthin interacts synergistically with other antioxidants, such as α-tocopherol, ascorbic acid, and glutathione, present in the lipophilic hydrophobic compartments of fish tissue, leading to positive effects, particularly in aquaculture (Nakano and Wiegertjes, 2020). Carotenoids are also vital for reproductive health. Beta-carotene is an essential carotenoid that promotes reproductive health, particularly in ruminant species. It improves ovulation and enhances pregnancy rates, as well as the generation of progesterone. Furthermore, it has been found that offspring of female animals treated with carotenoids develop faster (Mitsuishi and Yayota, 2024). Lutein and zeaxanthin are carotenoids that have been shown to improve eye health. These substances shield the retinal tissue in the eye from oxidative damage, preventing age-related vision loss (Nwachukwu et al., 2016). Lutein-containing feed additives for poultry and fish have been shown to improve vision and overall performance (Abdel-Aal et al., 2013). Carotenoids help to improve the quality of meat and eggs in poultry production. Carotenoids such as astaxanthin are used to improve meat color in salmon, while lutein and zeaxanthin make chicken egg yolks brighter and darker yellow (Pasarin and Rovinaru, 2018). This is critical to enhancing product quality and satisfying customer demands.

Carotenoids are natural antioxidants that provide many health benefits to animals when used as feed additives. They help with a variety of biological processes, including decreasing oxidative stress, strengthening the immune system, and maintaining reproductive and ocular health. Furthermore, their potential to improve meat and egg quality elevates the importance of carotenoids in feed formulations. The utilisation of carotenoids in the livestock industry is of paramount importance for the enhancement of animal productivity and the development of disease resistance.

Flavonoid and polyphenols

Flavonoids belong to the polyphenol family and are synthesized by plants. They are widely found in stems, leaves, flowers, and fruits (Nabi et al., 2020). Flavonoids are classified into subcategories such as flavanols, flavones, isoflavones, and anthocyanins, however, polyphenols form a larger category that includes subcategories such as tannins and lignans (Pandey and Rizvi, 2009). These compounds help to reduce oxidative damage in animal cells while also showing anti-inflammatory, immunomodulatory, and antibacterial properties (Scalbert et al. 2005). In recent years, an increasing number of studies have reported various benefits of flavonoids. Flavonoids are becoming a popular research topic in biology, food science, medicine, and other fields (Nabi et al., 2020). Flavonoids and polyphenols, which are plant-based feed additives, are known for their powerful antioxidant properties. They support the animal immune system (Bravo, 1998). Natural plant-based extracts containing flavonoids and polyphenols may be used as feed supplements. Plant materials such as grape skins, green tea, olive leaves, and citrus peels are rich sources of these compounds (Scalbert et al., 2005). The addition of these compounds to animal feeds improves nutritional quality while also providing a variety of health benefits to animals. Flavonoids and polyphenols prevent oxidative stress by neutralizing free radicals through their potent antioxidant capabilities. Oxidative stress, particularly in intensive production environments, leads to cellular damage in animals, resulting in reduced performance. This damage can be avoided by supplementing feed with flavonoids and polyphenols. Animals with higher levels of flavonoids and polyphenols are more resilient to infections and experience lower disease incidence rates, as these compounds enhance immune systems and provide protection against diseases through their antiviral and antibacterial properties (Bravo, 1998). Incorporating flavonoids into the diet helps reduce oxidative stress and enhances milk production in dairy cows (Olagaray and Bradford, 2019). It has been found that polyphenol supplementation reduces lipid peroxidation and improves immunological responses in chickens (Surai, 2014). Flavonoids and polyphenols have well-established immunological benefits. These compounds boost the immune system by activating macrophages, lymphocytes, and natural killer cells (NK cells) (Ioannone et al., 2013). Green tea catechins, for example, protect mice from infections by exhibiting antiviral and antibacterial properties (Xu et al., 2017). Flavonoid-enriched diets enhance the immune response and increase disease resistance in chickens. Additionally, by regulating inflammatory processes, polyphenols can help animals experience milder disease symptoms. Quercetin, a flavonoid derivative, has been shown to promote growth, prevent infections, and function as an antioxidant and antiviral in farm and poultry animals (Tan et al., 2022). Polyphenols also have positive effects on reproductive health. Grape seed extract, which contains polyphenols, can increase male reproductive efficiency by enhancing sperm quality (Koşal, 2023). Flavonoid supplementation in female animals boosts reproductive health by regulating ovarian function (Dai et al., 2021). Flavonoids and polyphenols help to keep the digestive tract functioning properly. Polyphenols have positive effects on the gut microbiota, inhibiting the development of harmful bacteria while promoting the growth of beneficial bacteria. This helps improve the digestive health of animals (Dueñas et al., 2015). Studies on the impact of flavonoid and polyphenol additives on the quality of meat and milk revealed that these compounds, with their antioxidant qualities, prolonged the shelf life of meat by inhibiting lipid oxidation and contributed to the preservation of its nutritious content (Beslo et al., 2023). According to a detailed review by Serra et al., (2021), adding polyphenols to animal feed improves animal-derived food products while having no negative effects on animal health. Food-derived polyphenols have been found to undergo few metabolic changes, thus enriching meat and dairy products (Beslo et al., 2023).

Flavonoid and polyphenol derivatives, when used as feed additives, improve animal health. They support biological functions, such as reducing oxidative stress in animals, strengthening the immune system, and improving reproductive and digestive health. Additionally, the positive effects on improving meat and milk quality support the use of these compounds as feed additives. Furthermore, polyphenols are regarded as non-toxic substances, which makes them a potentially more appealing option for consumers than their synthetic counterparts. The use of flavonoids and polyphenols in animal feed is an essential method for increasing production while also improving overall animal health.

Chitosan

Chitosan is used as an antioxidant in food products due to its significant antioxidant properties, which can delay lipid oxidation by chelating metal ions. Chitin and chitosan are high molecular weight polymers that are either insoluble in water or only partially soluble (as oligomers) and have a strong capacity for water retention. Arthropods and molluscs, including shrimp, oysters, crabs, and lobsters, are the primary source of

these materials. Recent research has concentrated on chitosan oligosaccharide (COS), a chitosan derivative that dissolves quickly in water due to its short chain length and free amino groups in D-glucosamine units (Kasnak and Palamutoğlu, 2015; Yılmaz et al., 2006; Keser and Bilal, 2010).

COS exhibits various biological functions, including anti-inflammatory and antioxidant activities. In the study conducted by Lin et al. (2025), chitosan oligosaccharides were shown to reduce lipopolysaccharide-induced inflammation and oxidative stress in bovine mammary tissue. COS also provides a more effective immune system function and has a protective effect against infections (Lin et al., 2025). Chitosan-containing feeds have been shown to improve immune response in laying hens (Chahar et al., 2024). In the study conducted by El-Zaiat et al., it was explained that chitosan-added feeds improved rumen fermentation in ruminant animals (El-Zaiat et al., 2025). The addition of chitosan oligosaccharides to feeds improves feed conversion rate in ruminant animals (Önenç and Ekşi, 2024). Dietary supplementation of chitosan improves milk performance in dairy cows, supports the antioxidant status of animals, and can reduce inflammation (Zheng et al., 2021). A study in weaned pigs revealed that chitosan increased the total antioxidant capacity and superoxide dismutase, catalase, and glutathione peroxidase activities in animals, and reduced glutathione content in serum. In the same study, it was stated that serum malondialdehyde and cortisol content decreased in animals with chitosan application, and therefore chitosan added to the feed regulated the immune response in pigs (Xu et al., 2018).

The use of chitosan as an animal feed additive offers many advantages. Among these; strengthening the immune system and providing protection against diseases, supporting digestion, accelerating growth and increasing feed efficiency, being natural and safe, improving rumen fermentation. Therefore, Chitosan and its derivatives have a place as a substance with a wide range of applications in animal nutrition.

Whey

Whey, a byproduct of cheese production, contains protein, lactose, fat, and minerals. Whey proteins contain sulfur-containing amino acids (cysteine and methionine), which make them natural antioxidants. Whey proteins include β-lactoglobulins, α-lactalbumin, immunoglobulins, serum albumin, lactoferrin, lactoperoxidase, and protease. Whey is a nutritious byproduct derived from fresh milk that is easily digested by calves, lambs, and goats. It contains no anti -nutritional elements and is rich in nutrients with high biological value. Eighty percent of the milk used in cheese production is obtained as whey. Whey is composed of 94% water, with the remaining 6% consisting of dry matter. Within this 6% dry matter, 77% is lactose (milk sugar, a disaccharide made up of galactose and glucose), 12% is crude protein (which includes milk proteins such as lysine, methionine, cystine, valine, alanine, histidine, sulfur amino acids, serine, β-lactoglobulins, and α-lactalbumin), and 10% is mineral matter (including milk minerals like calcium, phosphorus, magnesium, and potassium). Whey's pH ranges from 6 to 6.8 (Çetinkaya et al., 1997; Stock et al., 1986; www.Euromilk. Org).

Whey proteins are used in animal nutrition for their properties, such as water absorption, solubility, emulsification, gel formation, viscoelasticity, lipid binding, and their contribution to taste and aroma formation. The source of whey proteins is nitrogen and amino acids in cheese. Whey proteins have an excellent biological value, and new research indicates that they are good for animal health. Whey can reduce oxidative stress and prevent oxidation by binding iron (Kasnak and Palamutoğlu, 2015; Karagözlü and Bayarer, 2004; Harper 2004; German et al., 2000; Smithers et al., 1996).

Conclusion

In animal nutrition, additives are added to feeds to increase feed quality, improve animal health, extend product life, and enhance food quality. Among these additives, there is an increasing tendency towards natural antioxidants. Antioxidant feed additives positively affect growth performance, meat quality, and the immune system of animals. By reducing oxidative stress, they provide better health and high productivity, especially in stressed animals. The review concludes that antioxidant substances, which are closely related to natural feed additives, occupy a significant place in the livestock industry and that further detailed studies should be conducted on the subject.

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