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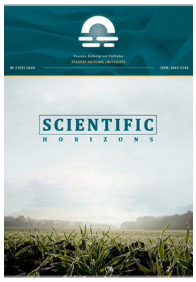

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The application of monoglycerides in swine husbandry: A review of current trends and prospects

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Abstract. The increasing prevalence of multi-resistant strains due to the widespread use of antibiotics in livestock farming represents a critical risk factor for both humans and animals. Therefore, the development of alternative strategies to replace antibiotics in animal production systems remains an urgent challenge. Various bioactive compounds have been proposed as alternatives; however, most fail to achieve efficacy comparable to that of antibiotics. The present review aimed to analyse recent studies regarding the effects and mechanisms of action of fatty acids and their glycerides on the digestive system of production animals. Mixtures of individual fatty acids and monoglycerides are considered promising substitutes due to their broad-spectrum antimicrobial, antiviral, anti inflammatory and metabolic effects. A key benefit of such mixtures is the maintenance of barrier integrity and immune function in the pig intestine under intensive farming conditions. Despite notable progress in the study of individual bioactive agents aimed at supporting pig productivity in the post antibiotic era, the molecular and cellular mechanisms underlying the effects of balanced blends of fatty acids and glycerides remain unclear. Recent evidence suggested that monoglycerides enhance resistance to infections, reduce mortality, and support consistent productivity in systems with limited antibiotic use. Reported findings indicated that individual monoglycerides improve intestinal morphology

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and enhance nutrient absorption efficiency. A significant aspect of their protective function is their ability to modulate the composition of the intestinal microbiota by selectively inhibiting the growth of pathogenic taxa. This review provided an overview of the key antimicrobial effects of monoglycerides. Collectively, these properties support the formulation of a scientifically grounded concept for entirely antibiotic-free livestock production. This concept may serve as an effective strategy for promoting sustainable pork production in line with modern standards. The review contributed to the understanding of both the limitations and potential of fatty acids and glycerides as alternatives to antibiotics

Keywords: monoglycerides; swine farming; immune system; intestinal morphology; microbiome; antibiotic resistance

INTRODUCTION

Global swine production is currently in a recovery phase following a crisis caused by the spread of African swine fever, which significantly reduced pig populations and pork production volumes in many countries, as well as the COVID-19 pandemic, which temporarily disrupted market activity. Global pork production is now exhibiting growth in both volume and price, operating within a context of intense competition, technological advancement and innovation. The intensification of pork production has facilitated the spread of disease, making it increasingly difficult to maintain productivity without the use of antimicrobial agents. Since the 1950s, growth promoters, including antimicrobial agents, have played a crucial role in enhancing animal productivity (Haulisah *et al.,* 2021). However, their use has led to a significant rise in antibiotic resistance. The European Union banned growth promoters in 2006 and introduced additional restrictions on the prophylactic use of antibiotics in 2018, which came into effect in 2022 (Jackman *et al.,* 2023). These restrictions have driven an active search for alternatives to antibiotics (Mykhalko, 2021; Szabó *et al.,* 2023). In the past decade, interest has compounded the alternative strategy concerning non-antibiotic growth promoters and antimicrobial substances to support animal health and enhance the profitability of swine farming.

In current livestock practices, there is increasing interest in the use of bioactive compounds as replacements for antibiotics in animal feed (Dahmer *et al.,* 2020). Among these compounds, monoglycerides and their derivatives are of particular interest. Monoglycerides offer several advantages in combating infectious diseases in animals compared to antibiotics. Firstly, they possess a broad spectrum of antimicrobial activity, inhibiting the proliferation of both viruses and bacteria, whereas antibiotics are only effective against bacteria. Secondly, pathogens face significant barriers in developing resistance to monoglycerides, making them effective not only for treatment but also for disease prevention (Tan *et al.,* 2021; López-Colom *et al.,* 2020). Third, monoglycerides are more effective than fatty acids and are safer than other organic agents, including formaldehyde, formic acid, and other acidifiers (Jackman *et al.,* 2022). Therefore, the application of monoglyceride blends as a replacement for antibiotics represents a promising approach in animal farming. The antimicrobial properties of monoglycerides depend on multiple mechanisms of pathogen suppression, while the selection for multi-resistant strains has not been observed among microbial populations. Taking into account that the emergence of multi-resistant strains represents one of the most critical global challenges, monoglycerides may offer a viable solution for developing alternative strategies to minimise both the presence of antibiotics in animal products and the risk of spreading multi-resistant strains.

This review was conducted using a systematic analysis of the available literature on organic acid and glyceride supplementation in swine farming. In addition, attention was given to the most important characteristics of these compounds to ensure their positive impact on both gut and overall animal health. The databases consulted included AGRICOLA, PubMed, Biological Abstracts, CAB Abstracts, the Index-Catalogue of Medical and Veterinary Zoology (ICMVZ), the International Veterinary Information Service (IVIS), and the Office International des Epizooties (OIE). Articles were included in the analysis if they contained at least two of the aforementioned keywords. This review provides a comprehensive overview of current data on the molecular mechanisms, potential, and effectiveness of monoglyceride application in swine production, and examines their impact on physiological state, productivity, and overall pig health. In addition, the authors discuss the effects of monoglycerides on the immune response, microbiome composition, and intestinal morphology. The is based on recent findings published in biomedical and veterinary medicine journals.

Thus, this review aimed to compile and clarify both foundational and recent data on the potential of monoglycerides as an alternative to antibiotics in swine farming.

GENERAL CHARACTERISTICS OF MONOGLYCERIDES

Monoglycerides are a class of glycerides consisting of a glycerol molecule covalently bonded to a fatty acid via ester linkage. Due to the presence of both primary and secondary hydroxyl groups in glycerol, there are two types of monoglycerides: 1-monoacylglycerols, where the fatty acid is attached to the first hydroxyl group, and 2-monoacylglycerols, where it is attached to the second hydroxyl group. Owing to their structure, monoglycerides possess both hydrophilic (water-attracting) and hydrophobic properties. Mono- and diglycerides are generally produced through the transesterification (glycerolysis) of triglycerides with glycerol (Panyod *et al.,* 2024). In industry, monoglycerides are primarily used as surfactants, typically in the form of emulsifiers. However, their most promising application appears to be as biologically active additives, providing a safe alternative to antibiotics and hormonal products.

Monoglycerides containing both short-chain and medium-chain fatty acids (SCFAs and MCFAs) exhibit direct antimicrobial effects *in vitro* and have the potential to enhance immune competence in animals, improve gut health, and reduce the risk of disease transmission in the postantibiotic era. SCFA α-monoglycerides, such as α-monopropionin and α-monobutyrin (derivatives of propionic and butyric acids), are primarily active against Gram-negative bacteria. In contrast, MCFA α-monoglycerides, such as α-monocaprylin, α-monocaprin, and α-monolaurin, are more effective against Gram-positive bacteria. Numerous studies have confirmed the antibacterial effects of α-monoglycerides *in vitro* and *in vivo*. Additionally, recent findings indicate that MCFA α-monoglycerides, particularly α-monolaurin, exhibit antiviral properties. P. Salvi and R. Cowles (2021) demonstrated that the biological activity of free butyric acid is associated with the regulation of cellular responses to maintain the viability and function of various cell types, including through histone deacetylase inhibition and G-protein-coupled receptor activation.

Medium-chain fatty acids (MCFAs) represent a class of saturated fatty acids containing from six to twelve carbon atoms. This class includes caproic, caprylic, capric, and lauric acids, which are present in natural products including cow's milk and vegetable oils extracted from coconut and the fruit of oil palms (López-Colom *et al.,* 2020). Mono-, di-, and triglycerides of MCFAs are typically formed via esterification with glycerol. Apart from serving as an energy source, MCFAs have demonstrated potential for improving gut morphology, stimulating growth, preventing infections, regulating immune responses, and functioning as alternatives to antibiotics (Dahmer *et al.,* 2020; Yu *et al.,* 2023). Several studies, including G. Chen *et al.* (2023), have shown that both mono- and triacylglycerols of DL-3-hydroxybutyrate are non-toxic, stimulate metabolic energy production upon intravenous administration, and can be used as nutrients in animal feed.

The primary structural feature responsible for the biological activity of monoglycerides (MGs) is the formation of micelles – self-assembled particles that form stable spheres once their concentration exceeds the critical micelle concentration (CMC). An increase in the length of hydrocarbon chains in the fatty acid residues of glycerides leads to stronger intramolecular hydrophobic interactions and alters the balance of micelle self-assembly (Yoon *et al.,* 2020). The nonionic nature of MGs allows them to form micelles at lower concentrations compared to MCFAs, which are anionic and subject to electrostatic repulsion (Feyaerts, 2022). Thus, the antimicrobial efficacy of MGs is related to the fatty acid composition and their ability to form micelles at lower concentrations. MGs exhibit inhibitory effects against a wide range of both bacteria and membraneenveloped viruses by disrupting their membranes. Recently, S. Tan *et al.* (2024) demonstrated that several fatty acids and monoglycerides exhibit significantly higher biological activity depending on the unique structure of their micelles, whereas the monomeric form of glycerides shows considerably lower or no activity. The antibacterial effects of MGs are associated with increased bacterial membrane permeability, local membrane damage, and the disruption of essential membrane functions, including electron transport, oxidative phosphorylation, and enzymatic activity (Casillas-Vargas *et al.,* 2021). MGs are also effective against membrane-enveloped viruses, where membrane disruption is a key component of their antiviral mechanism.

EFFECT OF MONOGLYCERIDES ON PERFORMANCE AND FEED CONVERSION IN PIGS

The supplementation of monoglycerides in pig diets has attracted particular attention due to their potential to improve productivity and feed conversion efficiency. This section examines the effects of MGs on growth, feed conversion, and overall pig health based on recent scientific research. A significant amount of conflicting data exists regarding the effects of SCFA- or MCFA-containing monoglycerides on the performance of weaned piglets (Cui *et al.,* 2020; Thomas *et al.,* 2020; Papadopoulos *et al.,* 2022). However, recent studies indicate that adding a monoglyceride blend to piglet diets reduces the growth-to-feed ratio in pigs infected with enterotoxigenic *Escherichia coli* (ETEC). C. Ren *et al.* (2019) reported that the addition of capric acid to piglet diets increased body weight gain and exhibited moderate antibacterial activity against *E. coli*. At the same time, studies have shown that a blend of monoglycerides composed of C4, C8, and C10 fatty acids did not affect broiler performance in birds infected with necrotic enteritis (Kumar *et al.*, 2021). Conversely, feed additives containing α-GML improved the growth performance of broilers, which was attributed to increased feed intake and enhanced gut health (Lan *et al.,* 2021). The application of α-GML also demonstrated a beneficial effect, enhancing antimicrobial efficacy in both sows and suckling piglets. Furthermore, α-GML supplementation stimulated weight gain in suckling piglets. The addition of α-GML to sow diets significantly increased ($P < 0.05$)

piglet body weight at weaning and improved overall crude fat digestibility in sows (Papadopoulos *et al.,* 2022).

Recent data have shown that a 0.1% dose of α-GML improves the performance and growth of weaned piglets and reduces post-weaning diarrhoea. The authors attribute these effects to improved nutrient digestion, suppression of systemic inflammation, maintenance of intestinal permeability, and promotion of a stable gut microbiota in piglets (Wei *et al.,* 2023). The addition of glycerol monolaurate to sow diets improves gut health in suckling piglets. Specifically, the results of GML supplementation demonstrated a significant increase in fat, lactose, and protein content in sow colostrum, while piglets exhibited a reduction in IL-12 concentration in the duodenum, and reductions in TNF-α, IL-1β, and IL-12 in the jejunum, as well as IL-1β in the ileum. These changes were accompanied by an increase in villus height, crypt depth, and the villus-to-crypt ratio in the small intestine of animals exposed to GML, compared with the control group (Zhao *et al.,* 2023). Together, these factors contribute to the growth and development of piglets.

The results obtained by J.T. Gebhardt *et al.* (2020) suggest that the addition of MCFAs to swine diets enhances growth performance, induces a prolonged immune response against PEDV infection, and has no effect on faecal microbial composition. The application of monoglycerides with lysolecithin in finishing pig diets reduces metabolic energy expenditure, improves weight uniformity within groups, and shortens the time required to reach the target slaughter weight, although feed conversion efficiency may decline (Gonzalez Sanchez *et al.,* 2022). Similar findings on feeding strategies aimed at minimising feed costs and improving pig performance have been reported by other researchers (Bassetto *et al.,* 2017). At the same time, the supplementation of a complex mixture containing lysolecithins, monoglycerides, and a synthetic emulsifier at a dose of 750 g/t in postweaning piglet diets significantly improves performance and enhances the digestibility of protein, fat, and fibre without increasing feed intake (Desbruslais *et al.,* 2023).

Thus, the use of monoglycerides and their derivatives in pig feeding has a stimulating effect on animal performance and health. Similar beneficial effects have been reported in animals challenged with infectious diseases. The inclusion of monoglycerides in pig diets demonstrates antimicrobial properties and enhances resistance to infectious diseases by reducing the incidence of diarrhoea and improving intestinal wall morphology.

EFFECTIVENESS OF MONOGLYCERIDES IN THE TREATMENT AND PREVENTION OF SWINE DISEASES

Nowadays, various MGs are widely proposed as feed additives in pig production to support intestinal health, improve feed conversion, and enhance the profitability of swine farming. MGs exhibit considerable potential to positively impact animal health due to their antimicrobial properties, which help reduce disease incidence and improve metabolic processes. Experimental data have demonstrated that MCFAs exhibit a high level of antimicrobial activity against various pathogens, including enveloped viruses, numerous bacterial taxa, pathogenic fungi, and protozoa (Coban, 2019). The study of fatty acids concerning their antimicrobial properties is well documented in the literature. The most common disease in piglets is post-weaning diarrhoea, which is often caused by the invasion and proliferation of enterotoxigenic *Escherichia coli* strain F18 or strain F4 in the small intestine. Clinical symptoms develop as profuse diarrhoea, stunted retardation in weight gain, rapid dehydration, and general weakness (He *et al.,* 2020). Recently, a study on glyceride blends containing butyric and valeric acids demonstrated the protective effects of these mixtures in reducing diarrhoea symptoms and supporting immunity in piglets co-infected with enterotoxigenic *E. coli* (López-Colom *et al.,* 2020). Specifically, pigs fed glycerides exhibited higher body weight, reduced diarrhoea severity, and lower levels of neutrophils and TNF-α in serum on day 4 post-inoculation. The use of an antimicrobial MCFA blend led to a significant reduction in the incidence of severe diarrhoea in weaned piglets challenged with enterotoxigenic *E. coli* F18. Furthermore, the supplementation of these fatty acids was accompanied by an increase in feed efficiency seven days post-inoculation. This blend also altered faecal microbiota diversity and the mucosal structure of the small intestine (Pluske *et al.,* 2021). Comparative analyses have shown that adding monoglyceride mixtures can enhance resistance to enteric pathogens in weaned piglets by lowering diarrhoea severity and mitigating both intestinal and systemic inflammation (Park *et al.,* 2024). However, the effectiveness of monoglycerides efficiency remains inferior to that of high doses of zinc oxide in treating diarrhoea symptoms.

The results of M. Tian *et al.* (2022) demonstrated that supplementation with a monoglyceride containing butyrate as a feed additive for pigs reduces the release of pro-inflammatory cytokines (TNF-α and interleukins) in the small intestine prior to enterotoxigenic *E. coli* infection via suppression of the NF-κB/MAPK-dependent pathway. Another study demonstrated that monoglycerides reduce the proliferative activity of porcine epidemic diarrhoea virus (PEDV), significantly inhibiting pathogen transmission among post-weaning piglets (Phillips *et al.,* 2022). Recent studies have shown that a blend of benzoic acid with probiotics, as well as with essential oils extracted from plants, exhibits a significantly greater protective effect against diarrhoea and enhances the performance of weaned piglets, compared with the application of benzoic acid alone (da Silva *et al.,* 2021; da Silva *et al.,* 2022).

Previous data have confirmed the ability of free MCFAs to inhibit viral proliferation. Various MCFAs, including capric (C10), lauric (C12), and myristic (C14) acids, have been described in several studies as antiviral agents (Jackman *et al.,* 2023). Similar to MCFAs, antiviral properties have also been reported for long-chain unsaturated fatty acids, such as oleic (C18), linoleic (C18:2), and linolenic (C18:3) acids, which are capable of suppressing the proliferation of herpes simplex virus (HSV), vesicular stomatitis virus (VSV), and Visna virus. Furthermore, other studies have demonstrated comparable antiproliferative efficacy of both MCFAs and glycerides derived from MCFAs against several retroviruses, including herpes simplex viruses types 1 and 2. Despite ongoing progress in the study of Seneca Valley virus (SVV) biology, there are currently no vaccines or effective chemical treatments for SVV-initiated infection. However, recent *in vitro* studies have shown that monolaurin can inhibit SVV replication with up to 80% high efficiency. Other *in vivo* studies have demonstrated that monolaurin can ameliorate clinical symptoms, reduce viral absorption and tissue damage, and preserve cell function in SVV-challenged piglets (Su *et al.,* 2023). Monolaurin significantly reduced inflammatory cytokine release and promoted interferon-γ production, thereby enhancing viral clearance. Researchers concluded that monolaurin could be a promising alternative or feed additive for the treatment of various viral infections in swine, including SVV.

The antiviral activity of caprylic, capric, and lauric acids, as well as GML, has been investigated in relation to African swine fever virus ASFV inhibition in liquids and feed. Effective compounds and dosages capable of inhibiting ASFV proliferation have been identified (Jackman *et al.,* 2023). The application of low GML doses exhibits limited effects on virus replication. However, relatively high doses of GML are highly effective, reducing virus replication by up to 99%. The onset of antiviral activity corresponded with the critical micelle concentration of GML, highlighting the crucial role of formulation in enhancing protective responses against ASFV (Jackman *et al.,* 2023). The use of modern nanotechnology enables the creation of more effective formulations without altering the chemical composition of bioactive substances. For example, natural GML has low water solubility and limited efficacy against gram-negative bacteria. It is noteworthy that nanoencapsulation not only enhances bioavailability but also reduces ecotoxicity (Lopes *et al.,* 2019).

Fatty acids and monoglycerides have proven effective against *Neisseria gonorrhoeae*. Microemulsions containing α-linolenic acid have shown efficacy in treating neonatal gonococcal ophthalmia (Belagal, 2024). In the absence of vaccines, monocaprin may serve as a novel prophylactic agent to prevent *N. gonorrhoeae* growth and colonisation, against which the bacterium is unable to develop resistance (Churchward *et al.,* 2020). Stress associated with piglet weaning suppresses digestion, absorptive capacity, and intestinal energy provision. Supplementation with MCFAs has been shown to improve nutrient absorption and stimulate energy metabolism, which is an important component in maintaining development, daily growth, and viability in weaned piglets (Cui *et al.,* 2022). MCFAs, such as hexanoic and octanoic acids, have shown significant anticandidal activity, as have long-chain fatty acids, including lauric acid.

Thus, given intense competition and increasing food safety requirements, the supplementation of monoglyceride blends could represent a promising strategy to replace antibiotics in intensive animal farming. Furthermore, the combined antimicrobial and metabolic effects of monoglycerides may be important factors in reducing the risk of antibiotic resistance and enhancing the profitability of swine production. Monoglycerides, known for their antimicrobial and anti-inflammatory properties, are emerging as promising additives to enhance immune and antioxidant systems in pigs. The effects of monoglycerides are directed towards strengthening immunity, reducing oxidative stress, and increasing overall resilience to enteric infections. Administering α-GML to piglets at a dose of 1,000 mg/kg increases the cytokine release, particularly IL-10, and modulates the activity of antioxidant enzymes (GSH-Px) in the blood of weaned piglets. Under these conditions, serum MDA and TNF-α concentrations decrease. However, no differences were found in T-AOC and SOD activity, or IL-6 concentration in serum (Wang *et al.,* 2023). It is suggested that α-GML enhances antioxidant capacity by modulating intestinal barrier function.

In pigs, administering 0.6% α-GML reduced levels of free radicals, including hydrogen peroxide and malonic dialdehyde, in the small intestine. In addition, the aforementioned α-GML supplementation significantly increased the activity of both catalase and superoxide dismutase in both the small and large intestine parts (Papadopoulos *et al.,* 2022). J. Zhang *et al.* (2024) reported evidence suggesting that various mechanisms of antioxidant capacity transfer from maternal blood to the foetus via the transplacental barrier have also been explored through the use of α-GML supplement during pregnancy. Analysis of the observed data confirmed an inverse correlation between the concentration of lipopolysaccharides in sow plasma and both inflammatory and oxidative stress parameters.

EFFECTS OF MONOGLYCERIDES ON INTESTINAL MORPHOLOGY AND MICROBIOME IN PIGS

Gut health is a key factor in ensuring optimal productivity in pigs and resilience to infectious diseases. The application of monoglycerides has demonstrated stimulatory and protective effects on the normal morphology of intestinal structures, the balance of gut microbiota composition, and sustainable gut physiology, particularly in maintaining intestinal barrier function (Masiuk *et al.,* 2023). Recent data have shown that supplementation with α-GML at a dose of 1.0 g/kg in piglets increased the ratio of villus height to crypt depth in the duodenum. On the other hand, this study demonstrated that villus height in the small intestine, particularly in the jejunum and ileum, was increased compared to unexposed piglets; however, no effect was observed on crypt depth in the same tissue samples (Wang *et al.,* 2023). Additionally, GML promotes an increase in goblet cell numbers (Cui *et al.,* 2020). Supplementation with MCFA-containing glycerides has shown beneficial effects on various gut cell types, including epithelial, goblet, and immune cells, in post-weaning piglets. *E. coli* infection is associated with a reduction in both villus height and crypt depth, which are widely recognised indicators of intestinal health. However, in piglets exposed to LPS, MCFAderived glycerides restored villus morphology and increased IgA levels in the blood. A similar effect was observed in the ileum, albeit with a less pronounced impact (De Keyser *et al.,* 2019). The α-GML-supplemented feed additive, administered at a dose of 1.0 g/kg, increased the relative abundance of *Firmicutes* by 17.87% and decreased the *Bacteroidota/Campylobacterota* ratio. Moreover, α-GML application upregulated two specific taxa – *Blautia* and *Lactobacillus* – in the cecum, while species from the genera *Alloprevotella, Campylobacter*, and *Eubacterium* were significantly downregulated in the intestines of piglets compared to unexposed controls (Wang *et al.,* 2023).

Gene expression analysis indicated that linoleic acid significantly enhances the expression of genes regulating key signalling pathways linked to the antioxidant system (NRF1 and PPARγ), cellular responses (ap2 and C/EBPα), and metabolic energy synthesis. Cell culture experiments involving linoleic acid (LNA) revealed a reduced phosphorylation level of PPARγ at the Ser112 site, compared with cells exposed to either palmitic or oleic acid. The lack of a significant difference in triacylglycerol levels following inhibition of PPARγ Ser112 phosphorylation suggests divergent metabolic pathways for dietary fatty acids in adipose tissue cells. Exposure to LNA significantly promotes adipose tissue accumulation through modulation of PPARγ phosphorylation (Yu *et al.,* 2017).

Supplementation with GML upregulated the expression of several genes, particularly those encoding tight junction proteins, including claudins, occludins, and zonula occludens-1, in the middle section of the small intestine. However, in the ileum of piglets, only zonula occludens-1 expression was upregulated. These findings provide evidence that GML supplementation exerts a protective effect on intestinal barrier integrity (Cui *et al.,* 2020). Further data from a study involving the administration of 0.6% glycerol monolaurate showed a significant increase in occludin expression in the intestines of piglets (Papadopoulos *et al.,* 2022). Additionally, the application of GML to sows enhanced the levels of tight junction proteins – including zonula occludens-1, occludins, and claudins – in the small intestine. This was accompanied by upregulation of mucin subfamily mRNA expression and defensin protein family levels in the piglet gut (Zhao *et al.,* 2023).

Capric acid reduces total intestinal length, while probiotics do not affect intestinal mass or length but increase villus width and crypt depth in the epithelial cells of the small intestine. MCFAs do not influence these parameters. Recent data obtained by S. Park *et al.* (2024) provide evidence that both fatty acids and probiotics exhibit strong antibacterial effects, although each targets different pathogens: specifically, capric acid suppresses *E. coli* growth, while probiotics inhibit *C. perfringens* proliferation. Sequencing of 16S rDNA confirmed that supplementing sows with GML alters colonic microbiome composition and reduces the relative abundance of *Escherichia-Shigella* (Zhao *et al.,* 2023). Thus, monoglycerides can positively affect intestinal morphology, particularly by increasing villus height and improving the villus-to-crypt ratio, thereby promoting more efficient nutrient absorption. Additionally, monoglycerides can modulate gut microbiota composition by reducing pathogenic bacteria and supporting the balance of beneficial microbial taxa.

CONCLUSIONS

Monoglycerides exhibit significant potential in maintaining swine production due to their antimicrobial, antiviral, and anti-inflammatory properties. They not only contribute to improved animal productivity but also provide essential protection against infectious diseases. The use of monoglycerides in pig feed has demonstrated high effectiveness in reducing the incidence of diarrhoea caused by bacterial infections, particularly *Escherichia coli*, by stabilising gut microbiota and strengthening the immune system. Additionally, they can improve intestinal morphological parameters, such as villus height and the villus-to-crypt ratio, thereby enhancing nutrient absorption and overall pig health. Monoglycerides also play a crucial role in stimulating the immune and antioxidant systems, reducing oxidative stress, and helping to maintain animal health under stressful conditions, such as weaning or intensive rearing. Their antioxidant properties protect cells from damage and reduce inflammation, which is critical for supporting healthy metabolism and increasing animal disease resilience. Given the current imperative to reduce antibiotic supplementation in animal husbandry, monoglycerides serve as an effective alternative to traditional antimicrobial agents.

Thus, monoglycerides represent a promising and safe feed additive for enhancing the productivity, health, and overall resilience of pigs. Their application contributes to reducing dependence on antibiotics, supporting stable productivity and competitiveness in swine production amid global challenges such as combating antibiotic resistance and meeting the growing demand for environmentally sustainable products. Further study is required to identify monoglyceride blends with targeted antimicrobial and growth-promoting properties that can enhance the profitability of swine farming.

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CONFLICT OF INTEREST

The authors declare no financial conflicts of interest or personal relationships relevant to this article.

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Застосування моногліцеридів у свинарстві: огляд сучасних тенденцій і перспектив

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Анотація. Зростання числа мульти-резистентних штамів через тотальне використання антибіотиків у тваринництві є критичним фактором ризику як для людини, так і тварин. Тому, створення альтернативних стратегій відмови від антибіотиків в технологіях вирощування продуктивних тварин залишається надзвичайно питанням. Різні біоактивні сполуки пропонуються в якості альтернативи, однак, такі засоби не виявляють співмірної з антибіотиками ефективності. Метою представленого огляду було проведення аналізу досліджених за останній час ефектів та механізмів дії жирних кислот та їх гліцеридів на травну систему продуктивних тварин. Перспективними замінниками розглядаються суміші окремих жирних кислот і моногліцеридів завдяки їх багато спрямованим антимікробним, противірусним, протизапальним та метаболічним ефектам. Важливим ефектом таких сумішей є підтримка бар'єрної та імунної функцій кишечника свиней в умовах інтенсивного виробництва. Незважаючи на суттєвий прогрес у дослідженнях окремих біоактивних засобів для забезпечення продуктивності свинарства в пост-антибіотичну еру, молекулярні і клітинні механізми дії збалансованих сумішей жирних кислот і гліцеридів залишаються не розкритими. Сучасні дані свідчать про те, що моногліцериди підвищують резистентність тварин до інфекцій, знижують падіж та забезпечують стабільну продуктивність в умовах обмеженого використання антибіотиків. Недавні результати показали, що моногліцериди покращують морфологію кишечника і підвищують ефективність поглинання поживних речовин. Важливим аспектом протективних ефектів моногліцеридів вважається їх здатність модулювати склад мікробіоти кишечника шляхом селективного пригнічення патогенних таксонів. В огляді представлений аналіз принципово важливих антимікробних ефекти моногліцеридів. Все це разом, дозволяє розробити науково обгрунтовану концепцію відмови від антибіотиків у тваринництві, що може бути ефективним інструментом для побудови стратегії сталого виробництва свинини у відповідності до сучасних стандартів. Огляд сприятиме розумінню як перспектив, так і обмежень застосування жирних кислот та гліцеридів як альтернативи антибіотикам

Ключові слова: моногліцериди; свинарство; імунна система; морфологія кишечника; мікробіом; стійкість до антибіотиків