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Effects of medium-chain fatty acids on growth performance, microbial attributes, and fat deposition in broiler chicken

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Abstract: Poultry are monogastric animals that share a fat tissue structure that is strikingly comparable to the fat in animal feed. This indicates that the kind and source of fat in animal diets can significantly impact the accumulation and composition of fatty tissue in the resulting carcass. Hence, feeding (or dietary) manipulation is one of the best and commonly employed management strategies to improve of gut health and function in broiler production. Medium-chain fatty acids (MCFAs) are fatty acids with six to twelve carbon atoms that are prevalent in coconut and palm kernel oils. Much research is being conducted on nutritional approaches to enhance gut health and lower the usage of antibiotics in poultry farming. The use of MCFAs as an antibiotic substitute has been shown to have significant positive effects on broilers' health and performance due mainly to their short pathways of absorption and oxidation. However, the fatty acid makeup of these feed additions may vary, and the results are sometimes inconsistent. Although supplementing hen diets with MCFAs can lower intermuscular and abdominal fat, the precise mechanics are not entirely understood. The distinct metabolic roles of fatty acids in chickens are linked to both the degree of saturation and the length of the chain. Detailed information on the effect of MCFAs on the growth performance, antimicrobial properties, and fat deposition in broiler chickens are summarised.

Keywords: fatty acids; monogastric animals; bactericidal; animal feed

Antimicrobial resistance (AMR) has become a focus of attention due to the usage of antibiotics as growth promoters in animal feed, which is associated with the potential emergence and spread of antimicrobial resistant microorganisms. Antibiotics are generally used to eliminate or to modify intestinal bacteria, thereby enhancing the growth rate and feed efficiency of the chickens. The extensive use of antibiotics in birds has led to the development of antibiotic-resistant bacteria in the

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gastrointestinal tract and drug residuals in meat. The global consumption of veterinary antimicrobials in 2020 is estimated at 99 502 tonnes (95% CI 68 535–198 052) (Mulchandani et al. 2023), and an increase of 11.5% to 104 079 tonnes by 2030 is projected (Tiseo et al. 2020). Therefore, in May 2018, the World Health Organization (WHO), Food and Agriculture Organization (FAO), and World Organisation for Animal Health (OIE) established a joint initiative to reduce antimicrobial usage in animal feed and to ban antimicrobials as growth promoters in animal production. This initiative is one of the most straightforward measures taken thus far.

Medium-chain fatty acids (MCFAs) are saturated fatty acids with a chain length between 6 and 12 carbon atoms. MCFAs include hexanoic or caproic acid (C6:0), octanoic or caprylic acid (C8:0), decanoic or capric acid (C10:0), and dodecanoic or lauric acid (C12:0) (Demirci et al. 2023; Szabo et al. 2023) (Figure 1). The natural resources of MCFAs comprise coconut oil and palm kernel oil, which contain approximately 45 g/100 g of the edible portion of abundant lauric acid (Roopashree et al. 2021), followed by capric acid (C10) and caprylic acid (C8) (Lopez-Colom et al. 2019).

On the other hand, dairy products contain primarily caprylic and capric acid, which are naturally found in the milk of various mammals, such as goats and cows (Schonfeld et al. 2016). The palmitic and oleic acids in palm and red palm oils represent up to 40–43% of fatty acids (Szabo et al. 2023). Pigs and poultry that are monogastric have a fat tissue structure that is closely comparable to the fat in animal feed. This finding indicates

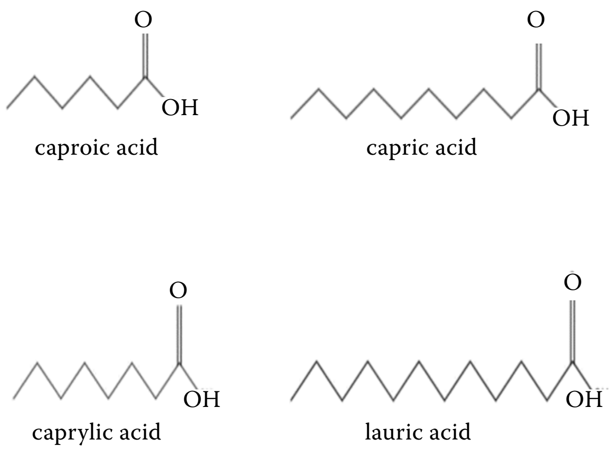

Figure 1. Molecular structures of medium chain fatty acids

that the kind and source of fat in animal diets can significantly impact the accumulation and composition of fatty tissue in the resulting carcasses (Baltic et al. 2018).

Because of their low fatty acid-binding protein affinity, MCFAs are diffused into the portal circulation, bonded to albumin, and delivered straight to the liver rather than being re-esterified inside the intestinal cells, where they are readily metabolised (Nguyen et al. 2018). In broilers, MCFAs that act as energy sources are poorly deposited in subcutaneous fat tissue (Baltic et al. 2018). Thus, the carcasses of broiler meat contain less fat with high commercial value and may provide greater insight into consumer feedback due to its nutritive value. Studies suggested that MCFAs have growth-promoting properties and can serve as alternatives to antibiotics and coccidiostats (Baltic et al. 2018; Oviedo-Rondon 2019; Szabo et al. 2023). Kumar et al. (2021) reported that a monoglyceride blend of MCFAs (butyric, caprylic, and capric acids) improved the overall feed efficiency of birds compared with the control group. In contrast, Wang et al. (2015) indicated that bird performance was not affected by feeding MCFA in the form of coconut oil. Scientific publications regarding the effect of MCFAs on broiler production are scarce and partly contradicting.

The mechanism behind MCFAs bactericidal activity is not fully understood. It is assumed that due to their lipophilic character, in undissociated form, MCFAs can reduce the intracellular pH that inactivates the bacterial cell and prevent bacteria from producing lipases that are required for the bacteria to adhere to the intestinal wall (Matsui et al. 2021). Based on a study by Timbermont et al. (2010), lauric acid caused a significant decrease in NE incidence (from 50% to 25%). Conversely, Yang et al. (2019) reported that lauric acid was not effective in reducing the incidence and severity necrotic enteritis.

Altogether, there is no distinct conclusion for growth performance and antimicrobial parameters regarding the supplementation of medium chain fatty acids in broiler chickens. The objective of this literature review is to explore the limitations and impact of MCFAs on growth performance and its antimicrobial effects in both *in vitro* trials and *in vivo* trials in broiler chickens. In addition, the effect of the fat deposition in correlation to MCFAs in broiler chickens will be discussed.

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Effects of MCFA on growth performance in broiler chickens

MCFAs have drawn more attention in the past ten years within the poultry industry as natural growth boosters because of their synergistic or additive impacts on intestinal health and growth performance. However, there have been various beneficial and controversial results reported in regards to MCFAs on growth performance in poultry. The inclusion of 1.5% of coconut oil in the broiler diet significantly increased the body weight in the 1–21-day period compared to canola oil, which significantly elevated the growth of broiler chicken during days 1–42 (Attia et al. 2020). Jadhav et al. (2021) described that 0.25% lauric acid and 0.25% capric acid alone or in combination resulted in better live body weight and cumulative weekly gain. Broilers that were fed the basal diet showed a higher feed conversion ratio (FCR) (from day 0 to day 42) than those fed MCFA-supplemented feed, having a lower FCR and a higher body weight (Baltic et al. 2018). Studies show that MCFA-supplemented broilers had lower feed intake but still maintained high average live weight gains and low FCRs (Belal et al. 2018). In contrast, Khatibjoo et al. (2018), Khosravinia (2015), and Wang et al. (2015) reported that, MCFA did not have any effect on growth performance for broiler chickens. Similarly, studies in rats by Takeuchi et al. (2006) and Shinohara et al. (2005) showed that feed intake and weight gain were not influenced by dietary MCFAs. These may be due to the discrepancies in the inclusion rate of dietary MCFAs on the growth performance among animal species.

Another possible explanation could be that one MCFA, octanoic acid, is a central signaling nutrient that acts via hypothalamic proopiomelanocortin (POMC) neurons to induce satiety and decrease appetite (Haynes et al. 2020). Dietary MCFAs are mostly absorbed directly into the hepatic portal vein (Kanta et al. 2023). The liver plays a significant role in the satiety-inducing effects of MCFAs by infusing the same quantities of MCFAs into the vena cava or the portal vein in fasting rats (de Sousa et al. 2006). Interestingly, MCFA infusion into the vena cava showed no impact in mice, despite a 40% reduction in food consumption during the first meal following portal vein infusion in rats (Geng et al. 2016). These findings imply that the brain senses elevated free fatty acid content in the liver or portal vein and regulates meal-ending satiation that partially contributes to the reduction in food intake.

Another report in rats indicates that inhibition of hepatic fatty acid oxidation (FAO) could stimulate an increase in feed intake (Horn et al. 2004), whereas an increase in hepatic FAO could have the opposite effect, a reduction in feed intake (de Sousa et al. 2006). Feeding with MCFAs led to more rapid oxidation in the liver of rats (Ooyama et al. 2009) due to its efficient absorption through the portal system. This absorption affects the energy balance that mammals usually maintain by changing the feed intake (Magni et al. 2009).

The discrepancy in the effects of MCFAs regarding the growth performance of broiler chickens may also be attributed to variances in the fat structure of MCFAs, which influence the molecular size and solubility in the watery intestinal content and can alter fats during digestion, absorption and transportation in tissues and organs (Baltic et al. 2018; Gomez-Osorio et al. 2021). Although important health benefits of MCFAs have been identified in *in vitro* models, direct addition of MCFAs in the animal feed has been limited due to their unacceptable odour and unpleasant taste (Baltic et al. 2018). Thus, a suitable inclusion rate of MCFAs of 0.25% will enable broilers to utilize the MCFAs that can be more efficiently resulting in improved growth performances (Jadhav et al. 2021).

Antimicrobial attributes of MCFAs in broiler chickens

Epidemiological studies show that poultry is one of the main reservoirs for zoonotic pathogens such as *Salmonella* and *Campylobacter* (Berthenet et al. 2019; Wibisono et al. 2020). Animal husbandry practices, including those related to nutrition and water management, can support the establishment of a healthy microbiome in the health and performance of livestock animals (Celi et al. 2017). Prebiotics, probiotics, and organic acids are common feed additives used to prevent the negative effects of pathogenic bacteria on chicken gut health due to the current ban on the use of antibiotics as growth promoters (Cenesiz and Ciftci 2020). MCFAs have recently garnered interest because of their possible beneficial antibacterial properties as antibiotic replacers (Jadhav et al. 2021).

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Some MCFAs such as lauric, capric, caprylic, and caproic acids, exhibit greater antibacterial potency than short-chain fatty acids, e.g. lactic and citric acids, due to their carbon atom chain length and degree of unsaturation rise (Jackman et al. 2020). In addition to their antimicrobial properties, Maele et al. (2016) evaluated MCFAs against *B. hyodysenteriae* using the broth dilution method and concluded that the longer the carbon chain and the lower the pH, the stronger is the antimicrobial activity of MCFA. MCFAs show more promising activity against Gram-positive bacteria than Gram-negative bacteria because of the different outer membranes of the bacteria structure (Yoon et al. 2018; Jackman et al. 2020). In addition, MCFAs inhibit the overgrowth of pathogenic bacteria since they have a higher pKa value than other organic acids (Gomez-Osorio et al. 2021). When MCFA penetrates the cell wall of bacteria, the bacterial cell will disintegrate and release protons to lower the intracellular pH. This will cause inactivation of cell enzymes to maintain a neutral cytoplasm that results in cell death (Giovagnoni et al. 2022). For instance, in an *in vitro* and *in vivo* study, MCFAs effectively inhibited the wild isolated avilamycin-resistant strains of *C. perfringens* type A and G (Kovanda et al. 2019). Kollanoor-Johny et al. (2012) and Van Immerseel et al. (2004) observed that caprylic acid (C8) decreased the colonisation of *Salmonella enteritidis* (SE) in young broiler chickens and turkeys, respectively. This finding may explain the significant reduction of SE in the above studies due to caprylic acid (C8), which had the most antimicrobial activity compared with other fatty acids and significantly reduced bacterial glucose utilisation (Skrivanova et al. 2004).

The targeted organ for the antibacterial effect is the intestine of the poultry (Clavijo et al. 2018). As shown in a study by Fortuoso et al. (2019), a faecal sample with a significantly reduced bacterial count of *E. coli* indicated that the antibacterial effect can be seen throughout the intestinal system. The bacterial reduction of *Salmonella* spp. and *Campylobacter jejuni* from the caecal sample also

Table 1. Antibacterial effect of MCFAs in *in vivo* and *in vitro* studies and the targeted organs

Bacteria	Method and organ of effect	Findings	References
Salmonella	*in vivo*; caecal and liver tissue	reduction of bacterial count colonisation at 0.30% caproic acid-treated broilers	Van Immerseel et al. (2004)
Salmonella enteritidis	*in vitro*	invasion assay showed decrease in bacterial invasion in 2 mM MCFA treated T84 cells	Van Immerseel et al. (2004)
Salmonella	*in vivo*; small intestine, caecum, cloaca, liver and spleen	feed supplemented with 0.70% to 1.00% caprylic acid reduced the *Salmonella enteritidis* count	Kollanoor-Johny et al. (2012)
S. aureus, B. cereus, S. thypimurium and *E. coli*	*in vitro*	the concentration of 5.00% lauric acid inhibited bacterial growth via the well diffusion method	Nitbani et al. (2016)
Campylobacter jejuni	*in vivo*; caecum	the bacterial count was significantly reduced post-21D infection for the diet treated with at 0.60% and 0.80% caprylic acid & capric acid, respectively	Gracia et al. (2016)
LAB, Enterococcus spp., *S. aureus* and *E. coli*	*in vivo*; ileum	MCFA (starter: 0.090%; grower: 0.070%; and finisher: 0.060%) reduced the bacterial count	Baltic et al. (2018)
E. coli	*in vivo*; intestine	the total bacterial count of *E. coli* was significantly reduced at 21D in the faecal sample for the diet treated with glycerol monolaurate at 200 mg/kg and 300 mg/kg, respectively	Fortuoso et al. (2019)

LAB = *Lactic acid bacteria*; MCFA = medium-chain fatty acid

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indicated that MCFA is able to reduce the pathogenic bacterial load in the small intestine (Van Immerseel et al. 2004; Kollanoor-Johny et al. 2012; Gracia et al. 2016). An *in vitro* study by Pereira et al. (2023) demonstrated that MCFAs can be absorbed at a faster rate as they are more water soluble, do not need the emulsification of bile and lipase and enters mitochondria without the need for carnitine. The upper gastrointestinal tract's acidic environment will keep MCFA mostly undissociated (Moquet et al. 2016). The impact of the antibacterial activity of MCFAs via *in vivo* and *in vitro* studies and the targeted organs are shown in Table 1.

These mechanisms explained that these fatty acids may have more bactericidal action in the distal portion of the intestine since they are not absorbed in the upper intestine and would not be liberated as free fatty acids without lipase activity that takes place in the duodenum (i.e. hindgut) (Gomez-Osorio et al. 2021). This finding might indicate that the antibacterial effect is most prominent in the proximal small intestine such as at the duodenum and jejunum. Therefore, there is a need to collect samples from different parts of the small intestine, such as digesta content from the duodenum, jejunum, or ileum to determine which part of the small intestine can have a consistent and larger antibacterial effect.

Fat deposition of MCFAs in broiler chicken

Poultry meat is the most consumed meat source. It is estimated that the average world consumption of poultry, pork, beef and veal, and sheep was 14.9 kg/capita, 11.1 kg/capita 6.3 kg/capita, and 1.8 kg/capita, respectively, in 2022. Poultry consumption in Malaysia is estimated to be 50.1 kg/capita (OECD 2023). Therefore, a quality product of poultry that is healthy and free from hazardous content is important for consumers.

A consistent scientific finding is that contributing factors for health issues related to obesity, cardiovascular disease, and cancer can be attributed to the type of meat that is consumed and the type of dietary fat (Pericleous et al. 2013; Ananthakrishnan et al. 2014). Some studies found that diets with lean broiler meat led to a body weight reduction and leaner muscle (Brennan et al. 2012). Therefore due to the increased consumer awareness of the health benefits, lean meat consumption, especially that of lean broiler meat, have been sought to achieve optimal health benefits (Li et al. 2005; Barosh et al. 2014).

There are few ways to manipulate the fat deposition in broiler meat. These methods consist of the diet content of the broiler feed, rearing environments, and genotypes of broiler birds (Tumova and Teimouri 2010; Wang et al. 2015). By manipulating the fatty acid profile in diets, the meat carcass quality can be influenced by different types of fats, which can be differentiated by the level of saturation, level of esterification, and fatty acid chain length (Wang et al. 2015). The fat digestion and metabolism of MCFAs is initiated with lingual and gastric lipases at the upper gastrointestinal tract and ends at the pancreatic lipase in the duodenum of the small intestine (Lemarie et al. 2016). Due to the high solubility of the MCFAs in water, the digestion of MCFAs happens more rapidly. Lingual and gastric lipases contribute to 15% to 20% of the whole lipolysis process (Carriere et al. 1993). These lipases activate the process to release the short and medium-chain fatty acids and trigger the reaction of pancreatic lipase (Gargouri et al. 1986) followed by absorption of some MCFAs by gastric mucosa. The remaining MCFAs will be digested by duodenal pancreatic lipase and absorbed at the small intestine.

Most MCFAs are absorbed in their free form with passive diffusion and are directly transferred as free fatty acids with albumin to the liver and into the portal circulation without re-esterification in the intestinal cells of rats (Ferreira et al. 2014). The majority of MCFAs do not depend on the carnitine transport mechanism into the mitochondria of the liver and are rapidly metabolised and oxidised for the production of energy in the liver of mice (Pereyra et al. 2023). As a result, the substrate availability for triglycerides synthesis in fat tissue and MCFAs are less likely to be stored in adipocytes (Bach et al. 1996). There are consistent studies that show that MCFAs can reduce fat deposition (Han et al. 2003). In a study in which coconut oil replaced soybean oil at 75%, abdominal and intermuscular fat reduction was achieved without compromising the growth in lean meat (Wang et al. 2015). Another trial with MCFA additive at 0.1% and middle chain triglycerides (MCT) additive at 6.4% also showed that an MFCA-supplemented diet is able to produce a leaner meat as the thigh lipid percentage and abdominal fat weight is significantly reduced

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(Chu and Chiang 2017; Khatibjoo et al. 2018). Further research into the meat fatty acid profile shows that an MCFA-supplemented diet is able to enrich broiler meat by changing the meat fatty acid profile (Chu and Chiang 2017). In a diet containing 0.2% of specific MCFAs (C8:0, C10:0 and C12:0), the total n-3 levels for the omega fatty acids were higher than that of the control group. Lauric acid, which was rarely found in the meat fatty acid profile, was also higher in the group receiving C12:0 additive (Demirci and Basalan 2021).

Broilers fed with MCFA-supplemented feed are also able to improve the blood serum lipid profile. In a trial with coconut oil replacement as the oil source in the diet, there was a reduction in low-density lipoprotein (LDL) cholesterol concentration and the ratio of LDL to high-density lipoprotein (HDL) cholesterol in the blood serum (Wang et al. 2015). Similar findings show reduced cholesterol levels in the blood serum with a diet supplemented with MCFA and combination MCFA with short chain fatty acid (SCFA) additive (Khatibjoo et al. 2018). For the triglycerides level in the blood serum, there were mixed results, as revealed in a study with MCFA supplementation, and triglycerides levels were elevated compared to the control diet (Baltic et al. 2018). In another trial with specific pure MCFA treatment, triglycerides levels were found to be reduced (Demirci and Başalan 2021). The effects of MCFA on the carcass quality, fat deposition and blood serum lipid profile of broiler chickens are presented in Table 2. It is hypothesised that the reduced levels could be attributed to the combined source of MCFAs provided in the treatment.

Table 2. Studies of MCFAs effects on the carcass quality, fat deposition and blood serum lipid profile in animals

No.	Source of MCFAs	Findings	References
1.	Rats fed isocaloric feed with medium-chain triglycerides and long-chain triglycerides	carcass quality: MCT (medium-chain triglycerides) fed rats have smaller fat depots	Han et al. (2003)
2.	Coconut oil versus soybean oil from DOC to 42D in broiler males	carcass quality: abdominal fat and subcutaneous fat thickness decreases as coconut oil intake increases; serum profile: Improved lipid profile with reduced total cholesterol, LDL cholesterol concentration and LDL/HDL cholesterol ratio	Wang et al. (2015)
3.	MCT concentration at 6.40% for all feed phases fed to broilers until 36D	carcass quality: total fat content and abdominal fat weight are reduced; for meat fatty acid profile, NEFAs increased in diet containing MCT	Chu and Chiang (2017)
4.	MCFA at 0.1% for all feed phases to broilers until 42D	carcass quality: reduced thigh meat lipid percentage with 10.2% and 8.68% for control and MCFA diet, respectively; serum profile: cholesterol were reduced	Khatibjoo et al. (2018)
5.	MCFA additive at (starter: 0.096%; grower: 0.072%; and finisher: 0.06%)	carcass quality: leaner meat as MCFA-treated group has higher carcass cut weight and percentage; serum profile: triglyceride concentration significantly increased in MCFA-treated broilers	Baltic et al. (2018)
6.	Specific MCFA (C8:0, C10:0 and C12:0) as different treatments provided at 0.2% for all feed phases fed to broilers until 42D	carcass quality: meat fatty acid profile showed significantly increased the level of total n-3 level in diet with MCT, group treated with C12:0 additive was found to have 1.06% lauric acid in meat fatty acid, which was usually absent; serum profile: triglycerides levels decrease in the MCFA treated group	Demirci and Basalan (2021)

DOC = day old chick; HDL = high-density lipoprotein; LDL = low-density lipoprotein; MCFAs = medium-chain fatty acids; MCT = middle chain triglycerides; NEFAs = non-essential fatty acids

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Further trials need to be conducted to confirm the triglycerides response to MCFAs.

The effect of reduced fat deposition and the alteration of meat fatty acid profile in broilers fed with MCFAs-supplemented diet will be an added beneficial property for health-conscious consumers. This extra effect can be another factor to consider during the formulation of the diet, especially for diets created for a specific market that needs enriched broiler meat. The MCFAs-supplemented diet can be achieved by replacing the oil source, such as palm kernel oil or coconut oil in replacement of an LCFAs oil source, such as palm oil or soy oil or by adding MCFA additive depending on the pricing of the oil source and the type of the effect needed from the MCFAs.

CONCLUSION

The results published in the literature show that MCFAs are another growth-promoter alternative that could control the intestinal health of broilers. Understanding the characteristics of MCFAs is critical to the application of the additive to animal diets. Regarding growth performance, the inclusion of MCFA plays an important role in determining the growth rate of broilers. At a suitable level of inclusion of MCFA, its fast absorption in the gut allows it to more efficiently utilise energy and allows broilers to have lower FCRs while maintaining the live weight, which will be economically beneficial. On the other hand, too high or too low of MCFA will cause inappetence in broilers, which will lead to poor performance due to lower nutrient intake as it has the effect of suppressing appetite at higher levels. Furthermore, the antibacterial effect is also highly dependent on the inclusion and type of MCFAs.

Various studies show that MCFAs are able to control the pathogenic bacteria in the gut microflora. However, as previously mentioned, the exact intestinal location that will have the most antibacterial effect needs to be determined as it is especially important in the application of diet in combination with the other non-antibiotic growth promoters, such as organic acids or probiotics. Further research is needed to confirm the degree of adipose tissue reduction and broiler meat fatty acid profile alteration of MCFAs. MCFAs can be used in feed formulation manipulation to produce enriched broiler meat for health-conscious consumers and to have leaner broiler meat. In conclusion, further understanding of the MCFAs will allow more accurate application of the additive into the diet to create a cost-effective or specialised diet suitable for broilers.

Conflict of interest

The authors declare no conflict of interest.

REFERENCES

Ananthakrishnan AN, Khalili H, Konijeti GG, Higuchi LM, De Silva P, Fuchs CS, Willett WC, Richter JM, Chan AT. Long-term intake of dietary fat and risk of ulcerative colitis and Crohn's disease. Gut. 2014 May 1;63(5):776-84.

Attia YA, Al-Harthi MA, Abo El-Maaty HM. The effects of different oil sources on performance, digestive enzymes, carcass traits, biochemical, immunological, antioxidant, and morphometric responses of broiler chicks. Front Vet Sci. 2020 Apr 28;7:181 p.

Bach AC, Ingenbleek Y, Frey A. The usefulness of dietary medium-chain triglycerides in body weight control: Fact or fancy? J Lipid Res. 1996 Apr 1;37(4):708-26.

Baltic B, Ciric J, Sefer D, Radovanovic A, Dordevic J, Glisic M, Boskovic M, Baltic MZ, Dordevic V, Markovic R. Effect of dietary supplementation with medium chain fatty acids on growth performance, intestinal histomorphology, lipid profile and intestinal microflora of broiler chickens. S Afr J Anim. Sci. 2018;48(5):885-96.

Barosh L, Friel S, Engelhardt K, Chan L. The cost of a healthy and sustainable diet – Who can afford it? Aust N Z J Public Health. 2014 Feb 1;38(1):7-12.

Belal SS. Efficacy of medium chain fatty acids and saccharomyces cerevisiae on growth performance of broiler. Bangl J Vet Med. 2018 Dec;16(1):31-8.

Berthenet E, Thepault A, Chemaly M, Rivoal K, Ducournau A, Buissonnieere A, Benejat L, Bessede E, Megraud F, Sheppard SK, Lehours P. Source attribution of Campylobacter jejuni shows variable importance of chicken and ruminants reservoirs in non-invasive and invasive French clinical isolates. Sci Rep. 2019 May 30;9(1):8098 p.

Brennan IM, Luscombe-Marsh ND, Seimon RV, Otto B, Horowitz M, Wishart JM, Feinle-Bisset C. Effects of fat, protein, and carbohydrate and protein load on appetite, plasma cholecystokinin, peptide YY, and ghrelin, and energy intake in lean and obese men. Am J Physiol Gastrointest Liver Physiol. 2012 Jul 1;303(1):G129-40.

https://doi.org/10.17221/175/2023-CJAS

Carriere F, Barrowman JA, Verger R, Rene L. Secretion and contribution to lipolysis of gastric and pancreatic lipases during a test meal in humans. Gastroenterology. 1993 Sep 1;105(3):876-88.

Celi P, Cowieson AJ, Fru-Nji F, Steinert RE, Kluenter AM, Verlhac V. Gastrointestinal functionality in animal nutrition and health: New opportunities for sustainable animal production. Anim Feed Sci Technol. 2017 Dec 1;234: 88-100.

Cenesiz AA, Ciftci I. Modulatory effects of medium chain fatty acids in poultry nutrition and health. Worlds Poult Sci J. 2020 Apr 2;76(2):234-48.

Chu HC, Chiang SH. Deposition of dietary bioactive fatty acids in tissues of broiler chickens. Poult Sci. 2017;54(2): 173-8.

Clavijo V, Florez MJ. The gastrointestinal microbiome and its association with the control of pathogens in broiler chicken production: A review. Poult Sci. 2018 Mar 1;97(3): 1006-21.

Demirci M, Basalan M. Effects of medium-chain free fatty acids on performance, some biochemical parameters and meat fatty acids profile of broiler chickens. Thai J Vet Med. 2021;51(2):339-46.

Demirci M, Evci S, Karsli MA, Senol A. Effects of free capric acid, lauric acid, and coconut oil supplementation on performance, carcass, and some blood biochemical parameters of broiler chickens. Turk J Vet Anim Sci. 2023; 47(2):138-45.

de Sousa UL, Arnold M, Langhans W, Geary N, Leonhardt M. Caprylic acid infusion acts in the liver to decrease food intake in rats. Physiol Behav. 2006 Feb 28;87(2):388-95.

Ferreira L, Lisenko K, Barros B, Zangeronimo M, Pereira L, Sousa R. Influence of medium chain triglycerides on consumption and weight gain in rats: A systematic review. J Anim Physiol Anim Nutr. 2014 Feb;98(1):1-8.

Fortuoso BF, Dos Reis JH, Gebert RR, Barreta M, Griss LG, Casagrande RA, de Cristo TG, Santiani F, Campigotto G, Rampazzo L, Stefani LM. Glycerol monolaurate in the diet of broiler chickens replacing conventional antimicrobials: Impact on health, performance and meat quality. Microb Pathol. 2019 Apr 1;129:161-7.

Gargouri Y, Pieroni G, Riviere C, Lowe PA, Sauniere JF, Sarda L, Verger R. Importance of human gastric lipase for intestinal lipolysis: an in vitro study. Biochem Biophys Acta Mol Cell Biol Lipids. 1986 Dec 5;879(3):419-23.

Geng CY, Zhang M, Li CY, Jin YH, Yan CG, Jin Y. Effectiveness of medium-chain fatty acids on feed intake and weight gain in animal: depending on balance. Indian J Anim Res. 2016;50(6):885-92.

Giovagnoni G, Tugnoli B, Piva A, Grilli E. Dual antimicrobial effect of medium-chain fatty acids against an Italian multidrug resistant Brachyspira hyodysenteriae strain. Microorganisms. 2022 Jan 27;10(2):301 p.

Gomez-Osorio LM, Yepes-Medina V, Ballou A, Parini M, Angel R. Short and medium chain fatty acids and their derivatives as a natural strategy in the control of necrotic enteritis and microbial homeostasis in broiler chickens. Front Vet Sci. 2021 Dec 14;8:773372.

Gracia MI, Millan C, Sanchez J, Guyard-Nicodeme M, Mayot J, Carre Y, Csorbai A, Chemaly M, Medel P. Efficacy of feed additives against Campylobacter in live broilers during the entire rearing period: Part B. Poult Sci. 2016 Apr 1;95(4):886-92.

Han J, Hamilton JA, Kirkland JL, Corkey BE, Guo W. Medium chain oil reduces fat mass and down regulates expression of adipogenic genes in rats. Obes Res. 2003 Jun;11(6):734-44.

Haynes VR, Michael NJ, van den Top M, Zhao FY, Brown RD, De Souza D, Dodd GT, Spanswick D, Watt MJ. A neural basis for octanoic acid regulation of energy balance. Mol Metabol. 2020 Apr 1;34:54-71

Horn CC, Ji H, Friedman MI. Etomoxir, a fatty acid oxidation inhibitor, increases food intake and reduces hepatic energy status in rats. Physiol Behav. 2004 Mar 1;81(1): 157-62.

Jackman JA, Boyd RD, Elrod CC. Medium-chain fatty acids and monoglycerides as feed additives for pig production: Towards gut health improvement and feed pathogen mitigation. J Anim Sci Biotechnol. 2020 Dec;11:1-15.

Jadhav P, Manwar S, Khose K, Wade M, Gole M, Langote G. Effect of medium chain fatty acids as replacement to antibiotics in diets on growth performance and gut health in broiler chicken. Ind J Anim Res. 2021;55(8): 894-9.

Kanta JM, Deisen L, Johann K, Holm S, Lundsgaard A, Lund J, Jahnert M, Schurmann A, Clemmensen C, Kiens B, Fritzen AM. Dietary medium-chain fatty acids reduce food intake via the GDF15-GFRAL axis in mice. Mol Metab. 2023 Aug 1;74:101760.

Khatibjoo A, Mahmoodi M, Fattahnia F, Akbari-Gharaei M, Shokri AN, Soltani S. Effects of dietary short-and medium-chain fatty acids on performance, carcass traits, jejunum morphology, and serum parameters of broiler chickens. J Appl Anim Res. 2018 Jan 1;46(1):492-8.

Khosravinia H. Effect of dietary supplementation of medium-chain fatty acids on growth performance and prevalence of carcass defects in broiler chickens raised in different stocking densities. J Appl Poult Res. 2015 Mar 1;24(1):1-9.

Kollanoor-Johny A, Mattson T, Baskaran SA, Amalaradjou MA, Hoagland TA, Darre MJ, Khan MI, Schreiber DT, Donoghue AM, Donoghue DJ, Venkitanarayanan K. Ca-

https://doi.org/10.17221/175/2023-CJAS

prylic acid reduces Salmonella Enteritidis populations in various segments of digestive tract and internal organs of 3-and 6-week-old broiler chickens, therapeutically. Poult Sci. 2012 Jul 1;91(7):1686-94.

Kovanda L, Zhang W, Wei X, Luo J, Wu X, Atwill ER, Vaessen S, Li X, Liu Y. In vitro antimicrobial activities of organic acids and their derivatives on several species of gram-negative and gram-positive bacteria. Molecules. 2019 Oct 19;24(20):3770.

Kumar A, Toghyani M, Kheravii SK, Pineda L, Han Y, Swick RA, Wu SB. Potential of blended organic acids to improve performance and health of broilers infected with necrotic enteritis. Anim Nutr. 2021 Jun 1;7(2):440-9.

Lemarie F, Beauchamp E, Legrand P, Rioux V. Revisiting the metabolism and physiological functions of caprylic acid (C8:0) with special focus on ghrelin octanoylation. Biochimie. 2016 Jan 1;120:40-8.

Li D, Siriamornpun S, Wahlqvist ML, Mann NJ, Sinclair AJ. Lean meat and heart health. Asia Pac J Clin Nutr. 2005 Jun 1;14(2):113-9.

Lopez-Colom P, Castillejos L, Rodriguez-Sorrento A, Puyalto M, Mallo JJ, Martin-Orue SM. Efficacy of medium-chain fatty acid salts distilled from coconut oil against two enteric pathogen challenges in weanling piglets. J Animal Sci Biotechnol. 2019 Dec;10(1):1-7.

Maele LV, Heyndrickx M, Maes D, De Pauw N, Mahu M, Verlinden M, Haesebrouck F, Martel A, Pasmans F, Boyen F. In vitro susceptibility of Brachyspira hyodysenteriae to organic acids and essential oil components. J Vet Med Sci. 2016;78(2):325-8.

Magni P, Dozio E, Ruscica M, Celotti F, Masini MA, Prato P, Broccoli M, Mambro A, More M, Strollo F. Feeding behavior in mammals including humans. Ann N Y Acad Sci. 2009 Apr;1163(1):221-32.

Matsui H, Imai T, Kondo M, Ban Tokuda T, Yamada Y. Effects of the supplementation of a calcium soap containing medium chain fatty acids on the fecal microbiota of pigs, lactating cows, and calves. Anim Sci J. 2021 Jan;92(1): e13636.

Moquet PC, Onrust L, Van Immerseel F, Ducatelle R, Hendriks WH, Kwakkel RP. Importance of release location on the mode of action of butyrate derivatives in the avian gastrointestinal tract. Worlds Poult Sci J. 2016 Mar;72(1): 61-80.

Mulchandani R, Wang Y, Gilbert M, Van Boeckel TP. Global trends in antimicrobial use in food-producing animals: 2020 to 2030. PLOS Global Public Health. 2023 Feb 1;3(2): e0001305.

Nguyen DH, Lee KY, Mohammadigheisar M, Kim IH. Evaluation of the blend of organic acids and medium-chain fatty acids in matrix coating as antibiotic growth promoter alternative on growth performance, nutrient digestibility, blood profiles, excreta microflora, and carcass quality in broilers. Poult Sci. 2018 Dec 1;97(12): 4351-8.

Nitbani FO, Siswanta D, Solikhah EN. Isolation and antibacterial activity test of lauric acid from crude coconut oil (Cocos nucifera L.). Procedia Chem. 2016 Jan 1;18: 132-40.

OECD – Organisation for Economic Co-operation and Development. OECD Stats: Meat consumption (indicator) [Internet]. 2023 [cit. 2023 Jan 12]. Available from: https://data.oecd.org/agroutput/meat-consumption.htm

Ooyama K, Kojima K, Aoyama T, Takeuchi H. Decrease of food intake in rats after ingestion of medium-chain triacylglycerol. J Nutr Sci Vitaminol. 2009;55(5):423-7.

Oviedo-Rondon EO. Holistic view of intestinal health in poultry. Anim Feed Sci Technol. 2019 Apr 1;250:1-8.

Pereira E, Fernandes JM, Goncalves R, Pinheiro AC, Duarte MS, Alves MM, Meirelles AJ, Maximo GJ, Vicente AA. Evaluating the in vitro digestion of lipids rich in medium-chain fatty acids (MCFAs) using dynamic and static protocols. Food Chem. 2023 Apr 16;406:135080.

Pereyra AS, McLaughlin KL, Buddo KA, Ellis JM. Medium-chain fatty acid oxidation is independent of L-carnitine in liver and kidney but not in heart and skeletal muscle. Am J Physiol Gastrointest Liver Physiol. 2023 Jul;325(4): G287-94.

Pericleous M, Mandair D, Caplin ME. Diet and supplements and their impact on colorectal cancer. J Gastrointest Oncol. 2013 Dec;4(4):409-23.

Roopashree PG, Shetty SS, Kumari NS. Corrigendum to effect of medium chain fatty acid in human health and disease. J Func Foods. 2021;87:104724.

Schonfeld P, Wojtczak L. Short- and medium-chain fatty acids in energy metabolism: The cellular perspective. J Lipid Res. 2016 Jun 1;57(6):943-54.

Shinohara H, Ogawa A, Kasai M, Aoyama T. Effect of randomly interesterified triacylglycerols containing medium-and long-chain fatty acids on energy expenditure and hepatic fatty acid metabolism in rats. Biosci Biotechnol Biochem. 2005 Jan 1;69(10):1811-8.

Skrivanova E, Savka OG, Marounek M. In vitro effect of C2–C18 fatty acids on salmonellas. Folia Microbiol. 2004 Mar; 49:199-202.

Szabo RT, Kovacs-Weber M, Zimboran A, Kovacs L, Erdelyi M. Effects of short-and medium-chain fatty acids on production, meat quality, and microbial attributes – A review. Molecules. 2023 Jan;28(13):4956.

Takeuchi H, Noguchi O, Sekine S, Kobayashi A, Aoyama T. Lower weight gain and higher expression and blood levels of adiponectin in rats fed medium-chain TAG compared with long-chain TAG. Lipids. 2006 Feb;41(2): 207-12.

Timbermont L, Lanckriet A, Dewulf J, Nollet N, Schwarzer K, Haesebrouck F, Ducatelle R, Van Immerseel F. Control of Clostridium perfringens-induced necrotic enteritis in broilers by target-released butyric acid, fatty acids and essential oils. Avian Pathol. 2010 Apr 1;39(2):117-21.

Tiseo K, Huber L, Gilbert M, Robinson TP, Van Boeckel TP. Global trends in antimicrobial use in food animals from 2017 to 2030. Antibiotics. 2020 Dec 17;9(12):918.

Tumova E, Teimouri AJ. Fat deposition in the broiler chicken: A review. Sci Agric Bohem. 2010;41(2):121-8.

Van Immerseel F, De Buck J, Boyen F, Bohez L, Pasmans F, Volf J, Sevcik M, Rychlik I, Haesebrouck F, Ducatelle R. Medium-chain fatty acids decrease colonization and invasion through hilA suppression shortly after infection of chickens with Salmonella enterica serovar Enteritidis. Appl Environ Microbiol. 2004 Jun;70(6):3582-7.

Wang J, Wang X, Li J, Chen Y, Yang W, Zhang L. Effects of dietary coconut oil as a medium-chain fatty acid source on performance, carcass composition and serum lipids in male broilers. Asian-Australas J Anim Sci. 2015 Feb; 28(2):223.

Wibisono FM, Wibison FJ, Effendi MH, Plumeriastuti H, Hidayatullah AR, Hartadi EB, Sofiana ED. A review of salmonellosis on poultry farms: Public health importance. Syst Rev Pharm. 2020;11(9):481-6.

Yang WY, Lee Y, Lu H, Chou CH, Wang C. Analysis of gut microbiota and the effect of lauric acid against necrotic enteritis in Clostridium perfringens and Eimeria side-by-side challenge model. PLoS One. 2019 May 31;14(5): e0205784.

Yoon BK, Jackman JA, Valle-Gonzalez ER, Cho NJ. Antibacterial free fatty acids and monoglycerides: Biological activities, experimental testing, and therapeutic applications. Int J Mol Sci. 2018 Apr 8;19(4):1114.

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