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Importance of medium chain fatty acids in animal nutrition

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Abstract. Fats in animal and human nutrition are a common subject of research. These studies most often pay attention to particular fat groups (saturated, unsaturated, polyunsaturated fats or fats grouped by the length of their fatty acid chains into short, medium or long chain fatty acids). Medium chain fatty acids (MCFAs) have two main sources: milk and coconut oil. To date, research has shown these acids have positive effects on health, production, feed digestibility and lower body and muscle fats in broilers and swine. MCFAs possess antibacterial, anticoccidial and antiviral effects. Also, it has been proven that these acids act synergistically if they are used together with organic acids, essential oils, or probiotics. Nowadays, commercial MCFA products are available for use in animal nutrition as feed additives.

1. Introduction

In recent years, replacing antibiotics in animal feedstuffs with biologically active substances has become a very current topic. The trend of banning the use of antibiotics, coccidiostats and other medical growth promoters in animal feedstuffs has developed because of fears these compounds contribute to the spread of bacterial resistance. Removing antibiotics from feedstuffs, after they were banned by the European Union (EU) in 2006, has put great pressure on livestock producers to find alternatives to antibiotics. Hence, modern feedstuff production is based on adding bioactive ingredients to feed, which should reduce the need for antibiotics and other medication, and positively influence animal health and welfare. In intensive breeding systems, these ingredients also reduce the negative influence of stress factors from the environment on animal immune systems and on animal production parameters. Consequently, in animal nutrition, more attention is now focused on competitive exclusion, probiotics, prebiotics, antibacterial peptides, yeasts and other additives. These additives also include medium chain fatty acids (MCFAs), which can be used in broiler and piglet nutrition. A variety of commercial MCFA products are already available on the market [1,2].

The structure of fat tissue of monogastric animals (pigs, poultry) is very similar to the fat structure of the feedstuffs on which the animals are fed. This means that source and type of fat in an animal feed can greatly influence the composition of fatty tissue and deposits in the resultant carcasses [3,4,5]. Nowadays, the EU policy of food modification is transferring from large-scale, cheap production to more expensive production, but hopefully with safer final food products. Clearly, the topic of modern animal feed additives is extremely relevant for the health and well-being of human consumers of the resultant meats.



2. Fat and fatty acids in human and animal diets

The term fats and oils, regardless of the animal or vegetable origin of these compounds, is a synonym for lipids that are used in human and animal nutrition. Besides their importance in body energy systems (they are both a source and a storage means of energy), they induce better resorption of liposoluble vitamins, slow down food passage through the intestine and, therefore, enable better exploitation of the food. They also increase the efficiency of energy consumption, as well as acceptability of the food. The energy value of the fats and oils in food and feed depends on numerous contributors, such as length of the carbon chain, specific organization of saturated and unsaturated fatty acids in the glycerol molecule, structure of free fatty acids, structure of the food/feed, amounts and types of triglycerides added to food/feed, and the intestinal flora, species, sex and age of the human/animal [6].

Fatty acids are variable by the chain length and degree of saturation. Chain length can vary from 2 to 40 carbon atoms, but the most common fatty acids contain 12 to 22 C atoms. Fatty acids are commonly categorized as short chain (SCFA; up to 4 C), medium chain (MCFA; from 6 to 12 C) and long chain (LCFA; more than 12 C). Additionally, they are categorized by the number of double bonds they contain; saturated fatty acids (SFA) have no double bonds in their fatty acid chain; monounsaturated fatty acids (MUFA) have one double bond in their fatty acid chain, and; polyunsaturated fatty acids (PUFA) have more than one double bond in their fatty acid chain. MCFA are a group of fatty acids with 6 to 12 C atoms obtained from edible fats such as coconut oil and milk fat by lipid fraction separation. Commercial MCFA products usually have 8 to 10 C atoms [7].

Differences in fat structure between MCFA and LCFA influences molecule size and water solubility, and also can result in differences during digestion, absorption and transportation of these fats in tissues and organs. Long term usage of MCFA in livestock feedstuffs, because of differences in the energy ratio between MCFA and LCFA and differing effects the two fat types have on intake, transport and efficiency of utilization, can influence the energy balance in animals [8,9]. Among the differences observed between MCFA and LCFA in animal feeds, these two types of fatty acids, according to their chain length and degree of saturation, must pass different metabolic pathways.

Fatty acid metabolic differences between the two fat types begin in the digestive tract, where MCFA is absorbed more efficiently than LCFA. Pigs can partly absorb MCFA via their stomachs. Medium chain triglycerides from MCFAs (MCTs) can be absorbed by intestinal enterocytes, after which they are hydrolyzed by the microsomal lipase. Compared with LCFA, MCFAs undergo simpler degradation to fatty acid and glycerol with help of pancreas lipase, after which they are absorbed via the portal circulation and transported to the liver where they undergo fast oxidation. LCFAs, as chylomicrons, are transported by the lymphatic system [10]. However, MCFAs are mostly saturated fatty acids, so they have great oxygenic stability, much higher so than LCFAs. This difference in the structure between LCFAs and MCFAs is reflected in the biological processes utilizing them. There are also differences in ketogenic and lipogenic capacity for these two groups of fatty acids. MCFA enter the mitochondria independently of the carnitine transport system and undergo preferential oxidation. Variations in ketogenic and lipogenic capacity also exist [8,11].

Alongside their energy value, bioactive fatty acids such as MFCAs, linoleic acid (C18:2) and linolenic acid (18:3) (these latter two fatty acids are categorized as essential fatty acids) have significant influence on human and animal health [12]. The most frequently mentioned characteristic of MCFAs is their ability to reduce obesity and fat tissue. This effect first was proven in rats, pigs and broilers [13,14,15]. The antidiabetic influence of MCFAs on humans with diabetes type 2 has only rarely been discussed [16]. MCFAs as sources of energy are poorly stored in subcutaneous fat tissue of humans, rats, broilers and pigs. In broilers and especially in pigs, this has special meaning because carcasses with less fat have higher commercial value, and this kind of meat is more in demand by consumers. In broiler meat, the presence of C6:0 has not been proven, but the content of C10:0 was higher than of C8:0. The content of C10:0 and C8:0 in chicken leg muscle and breast meat increased with increasing percentage of this fatty acid in feed for broilers [16].

In modern pig production, piglets are weaned and start to eat feed when they are between 15 and 28 days old. Feed consumption data indicated that digestive tracts of such young piglets are not yet developed, so they cannot use all the nutrition available from feed [17]. This low intake causes poor energy intake which negatively influences growth and development of the piglets. Digestibility of LCFAs is decreased by 65% to 80% in these young piglets compared with older animals, as result of low pancreas and intestinal lipase activity, which causes insufficient fat absorption from the digestive system. Also, in this period of life, piglets cannot synthesize enough carnitine, which has an important negative influence on transportation of LCFAs into mitochondria for energy production [18]. Moreover, unsaturated bonds in LCFAs can be damaged by free radicals, which can cause cascade damage to endogenous lipids and peroxide occurrence [19]. However, MFA is a good supplement for weaned piglets. Individually, MCFAs have an unacceptable odor, and so their triacylglycerols (medium chain triacylglycerols; MCTs) have usually been added to feed for animals [20]. Effects MCTs, or MCFA, or mixtures of two or all four important MCFAs (caproic acid (C6), caprylic acid (C8), capric acid (C10) and lauric acid (C12)) as supplements for growing piglets depend on the amount added. The life stage when piglets are fed MCFA also influences piglet growth [21,22].

Broilers, in their first days of life, have limited fat absorption and limited digestion capability, because of their low amounts of synthesized bile salt and lipase. In young individuals, fat digestibility is 6% less than in adult birds [23], but the young animals have far better ability to digest PUFA [22]. MCFAs have specific nutritive value and metabolic and antibacterial effects in poultry [24,25,26]. In egg production, usage of MCFA gave better results, eggs had stronger shells, and greater egg protein quality (larger Haugh units), higher content of calcium, and reductions in the number of *Escherichia coli* bacteria [27] resulted.

Pigs which have been fed with feed supplemented with MCFAs had better growth performance [8,28]. Digestibility of MCTs is much higher (98.5 instead 93.4%) than long chain triacylglycerols (LCTs) in weaned piglets. With two to five weeks of receiving MCTs, the digestive system of weaned piglets is fully functional for normal digestion and exploitation of nutritive components and energy from feed [8]. These authors showed that MCTs have a positive effect on production results, feed digestibility, blood plasma metabolites and antioxidant capacity of weaned piglets [8]. Digestibility of proteins and higher concentrations of protein in blood plasma especially stand out [8].

3. MCFA and microbiota of animal digestive tract

The role of SCFAs and MCFAs in control of infection and maintenance of health and integrity of digestive tract was examined in broilers [28] and other animals [29]. Fatty acids are generally inhibitory to microorganisms, but different fatty acids have different minimum inhibitory concentrations (MIC), depending on the type of fatty acid, type of microorganism and environmental pH. Low pH increases the concentration of dissociated SCFA, which in that conformation, can pass into the bacterial cells where the intercellular pH is higher. This higher pH dissociates the SCFA, so intracellular pH decreases and subsequently changes the bacterial cell's metabolism [29].

MCFAs produce a strong antibacterial effect due to the anionic part of the molecule, but how much effect is due to change of the bacterial pH and how much is due to influence on the metabolic level of the bacteria is not yet known. The anionic part of fatty acids changes the physico-chemical characteristics of the digestive tract environment in which the microorganisms exist, and influences the expression of microorganism and host genes. The molecular basis of the mechanism by which MCFA decrease numbers of *Salmonella* spp., *Clostridium* spp. and *E. coli* in the digestive tract is still unclear, but it has been proven that MCFA decreases the number of intracellular lymphocytes in epithelium cells of the digestive tract [29]. Additionally, the anticoccidial properties of MCFAs have been proven [30,31] by studying high quality coconut oil (enhanced virgin coconut oil – EVCO) that contains MCFAs and their proper monoglycerides [31]. These materials also inhibited growth of both Gram-positive and Gram-negative bacteria and the yeast, *Candida albicans* [31].

The structure of intestinal microbiota has important influences on the animal's ability to digest feed properly, causing positive, negative and neutral effects [32]. Modification of gastrointestinal

microbiota reduced colonization of the animals with pathogenic microorganisms, which can have a big influence on intestinal wall structure [33]. For example, Uni et al. [34] established that stress (delayed access to feed after hatching, exposure to bacteria, etc.) is related to changes in intestinal morphology, such as shorter intestinal villus cells and depth crypts. The immune system of newly-hatched chickens, especially the mucosal immune system, requires oral intake of feed for full and fast development.

Hermans et al. [35] reported that usage of MCFA emulsion in drinking water for broilers decreases the number of *Campylobacter* in their digestive tracts, and posited that this may especially be due to the lowered possibility that water acted as a source of these pathogens. MCFA are new generation additives, and can be used for *Salmonella* control. Broilers fed with MCFAs and organic acids performed better than control broilers, because they had better feed digestibility and lower numbers of *Salmonella enterica* Enteritidis in the cecum [36]. Immersell et al. [37] determined that usage of MCFA significantly reduced the level of *S. enterica* Enteritidis colonization when broilers were infected the third day after adding MCFA in feed. Zeiger et al. [38] used lauric acid in broiler feed, and found statistically significantly reduced numbers of *Campylobacter* on the carcasses.

4. MCFA and synergistic effects with other feed additives

Adding SCFA and MCFA in feed has numerous positive effects on animal health that can be seen when health of the animals is endangered, especially by compromised integrity of digestive tract. Mathis et al. [39] proved that the combination of organic acids and MCFA significantly reduced clinical symptoms of diseases in artificial necrotic enteritis of broilers. Almo et al. [39] showed in broilers infected with viral malabsorption syndrome (MAS) that adding SCFA and MCFA together in feed increased broiler growth and resulted in bigger broiler weight at the end of the production cycle. How this directly impacts viruses is not known, but it is considered that SCFA and MCFA together have a synergistic effect on bacteria, whereby MCFA damages microorganisms' cell walls, thus allowing SCFA access into the bacterial cytoplasm to produce an antibacterial effect [40]. Fat, protein and crude fiber digestibility can be improved if MCFA is used with selected organic acids (propionic, fumaric). This combination increases intestinal villi and crypt depths but does not affect villus width, so the ratio between villus height and crypt depth is more favorable. Use of MCFA (C6 and C8) and plant extracts (thymol, cinnamon oil, eucalyptus oil) in turkey nutrition increased bird weight after 15 weeks of fattening and did not influence total feed intake, but caused better feed conversion [41]. Adding MCFA to animal feed can be used in parallel with probiotics (e.g. *Enterococcus faecium*), giving weaning piglets better productivity, increased feed digestibility and changed biochemical blood profile (cholesterol, triglyceride, glucose, creatinine) [42]. The authors stressed that MCFA and probiotic together had a synergistic effect on piglet nutrition, and this effect should be an effective replacement for antibiotics [42]. Zeits et al. [43] used a different ratio of C12 and C14 in broiler nutrition. They did not measure any differences in microbiota, intestine morphology, or fat or cholesterol content in meat or liver, but adding MCFA had a positive effect on feed conversion and pectoral weight of broilers [43]. Using SCFA and MCFA in parallel in broiler nutrition had a positive effect on health and production results (live weight, weight of pectoral muscle, growth, feed intake and digestibility) [43]. The parallel use of MCFA and coccidiostats positively influenced production results in broilers (weight at the end of the production cycle, body weight, feed intake, growth, conversion) [44].

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References

- [1] Baltić Ž M, Marković R and Đorđević V 2011 Nutrition and meat quality *Tehnologija mesa* **52** pp 154-159
- [2] Šefer D, Marković R, Nedeljković-Trailović J, Petrujkić B, Radulović S and Grdović S 2015

- Primena biotehnologije u ishrani životinja, The application of biotechnology in animal nutrition *Veterinarski Glasnik* **69** pp 127-137
- [3] Baião N C and Lara L J C 2005 Oil and fat in broiler nutrition *Rev. Bras. Cienc. Avic.* **7** pp 129-141
- [4] Đorđević V, Đorđević J, Baltić Ž, Laudanović M, Teodorović V, Bošković M, Peurača Mile and Marković R 2016 Effect of sunflower, linseed and soybean meal in pig diet on chemical composition, fatty acid profile of meat and backfat, and its oxidative stability *Acta Veterinaria* **66** pp 359-372
- [5] Đorđević J, Pantić S, Bošković M, Marković R, Dokmanović-Starčević M, Baltić T, Laudanović M and Baltić Ž M 2015 Uticaj konjugovane linolne kiseline na masnokiselinski sastav i senzorne osobine suvog svinjskog vrata *Tehnologija mesa* **56** pp109-120
- [6] Ratnayake W N and Galli C 2009 Fat and fatty acid terminology, methods of analysis and fat digestion and metabolism: a background review paper *Ann. Nutr. Metab.* **55** pp 8-43
- [7] Babayan V K 1987 Medium chain triglycerides and structured lipids *Lipids* **22** pp 417-420
- [8] Li Y, Zhang H, Yang L, Zhang L and Wang T 2015 Effect of medium-chain triglycerides on growth performance, nutrient digestibility, plasma metabolites and antioxidant capacity in weanling pigs *Animal Nutrition* **1** pp 12-18
- [9] Hanczakowska E 2017 The use of medium chain fatty acids in piglet feeding—a review *Ann. Anim. Sci.* DOI: 10.1515/aoas-2016-0099
- [10] Ooyama K, Kojima K, Aoyama T and Takeuchi H 2009 Decrease of food intake in rats after ingestion of medium-chain triacylglycerol *J. Nutr. Sci. Vitaminol.* **55** pp 423-427
- [11] Papamandjaris A A, MacDougall D E, and Hones P J H 1998 Medium chain fatty acid metabolism and energy expenditure: obesity treatment implications *Life sci.* **62** pp 1203-1215
- [12] Aluko R E 2012 *Functional foods and nutraceuticals* p. 22 New York: Springer.
- [13] Takeuchi H, Noguchi O, Sekine S, Kobayashi A and Aoyama T 2006 Lower weight gain and higher expression and blood levels of adiponectin in rats fed medium-chain TAG compared with long-chain TAG. *Lipids* **41** pp 207-212
- [14] Newport M J, Storry J E and Tuckley B 1979 Artificial rearing of pigs: 7*. Medium chain triglycerides as a dietary source of energy and their effect on live-weight gain, feed: gain ratio, carcass composition and blood lipids *Br. J. Nutr.* **41** pp 85-93
- [15] Mabayo R T, Furuse M, Kita K and Okumura J 1993 Improvement of dietary protein utilisation in chicks by medium chain triglyceride *Br. Poult. Sci.* **34** pp121-130
- [16] Chu H C and Chiang S H 2017 Deposition of Dietary Bioactive Fatty Acids in Tissues of Broiler Chickens *Int. J. Poult. Sci.* **54** pp 173-178
- [17] Wu G 1998 Intestinal mucosal amino acid catabolism *J. Nutr.* **128** pp 1249-1252
- [18] Cera K R, Mahan D C and Reinhart G A 1988 Weekly digestibilities of diets supplemented with corn oil, lard or tallow by weanling swine *J Anim Sci* **66** pp 1430-1437
- [19] Fritz I B and Yue K T 1963 Long-chain carnitine acyltransferase and the role of acylcarnitine derivatives in the catalytic increase of fatty acid oxidation induced by carnitine *J. Lipid Res.* **4** pp 279-288
- [20] Oprean L, Iancu R, Stan R and Trașcă C 2011 Comparison between types of feeding on goat milk composition *JASB* **44** pp 76-79
- [21] Devi S M and Kim I H 2014 Effect of medium chain fatty acids (MCFA) and probiotic (*Enterococcus faecium*) supplementation on the growth performance, digestibility and blood profiles in weanling pigs *Veterinarni Medicina* **59**
- [22] Hanczakowska E, Świątkiewicz M, Natonek-Wiśniewska M and Okoń K 2016 Medium chain fatty acids (MCFA) and/or probiotic *Enterococcus faecium* as a feed supplement for piglets *Livest Sci* **192** pp 1-7
- [23] Freitas E R, Sakomura N K, Neme R and Santos A L D 2005 Valor energético do óleo ácido de soja para aves *Pesq. agropec. bras.* pp 241-246

- [24] Wiseman J 1984 Assessment of the digestible and metabolizable energy of fats for non-ruminants. In: Wiseman J. Fats in animal nutrition. London: Butterworths 1984. pp 277-297
- [25] Skřivanová E, Molatová Z, Skřivanová V and Marounek M 2009 Inhibitory activity of rabbit milk and medium-chain fatty acids against enteropathogenic *Escherichia coli* O128 *Vet. Microbiol.* **135** pp 358-362
- [26] Batovska D I, Todorova T, Tsvetkova V and Najdenski H M 2009 Antibacterial study of the medium chain fatty acids and their 1-monoglycerides: individual effects and synergistic relationships *Pol. J. Microbiol.* **58** pp 43-47
- [27] Lee S I, Kim H S and Kim I 2015 Microencapsulated organic acid blend with MCFAs can be used as an alternative to antibiotics for laying hens *Turk. J. Vet. Anim. Sci.* **39** pp 520-527
- [28] Hong S M, Hwang J H and Kim I H 2012 Effect of medium-chain triglyceride (MCT) on growth performance, nutrient digestibility, blood characteristics in weanling pigs *AJAS* **25** pp 1003-1008
- [29] Deschepper K, Gantois I, Maertens L and Van Meenen E 2013 A balanced mixture of medium chain fatty acids improves zootechnical performances and slaughter results of broilers *In Proceedings of the 19th European Symposium of Nutrition* PPV 10
- [30] Price K L, Lin X, Van Heugten E, Odle R, Willis G and Odle J 2013 Diet physical form, fatty acid chain length, and emulsification alter fat utilization and growth of newly weaned pigs *J. Anim. Sci.* **91** pp 783-792
- [31] Lückstädt C and Mellor S 2011 The use of organic acids in animal nutrition, with special focus on dietary potassium diformate under European and Austral-Asian conditions *Recent Adv Anim Nutr Aust* **18** pp 123-130
- [32] Lensing M, Van der Klis J D, Fabri T, Cazemier A and Else A J 2010 Efficacy of a lactylate on production performance and intestinal health of broilers during a subclinical *Clostridium perfringens* infection *Poult Sci* **89**(11) pp 2401-2409
- [33] Sato H, Nitana A, Kurosawa T and Oikawa S 2004 Anticoccidial efficacy of medium-chain triglycerides (MCT) in calves *J Vet Med Sci* **66**(12) pp 1583-1585
- [34] Garrido M N, Skjervheim M, Oppegaard H and Sørum H 2004 Acidified litter benefits the intestinal flora balance of broiler chickens *Appl Environ Microbiol* **70**(9) pp 5208-5213
- [35] Uni Z, Smirnov A and Sklan D 2003 Pre-and posthatch development of goblet cells in the broiler small intestine: effect of delayed access to feed *Poult Sci* **82**(2) pp 320-327
- [36] Hermans D, Martel A, Garmyn A, Verlinden M, Heyndrickx M, Gantois I, Haesebrouck F and Pasmans F 2012 Application of medium-chain fatty acids in drinking water increases *Campylobacter jejuni* colonization threshold in broiler chicks *Poult Sci* **91**(7) pp 1733-1738
- [37] Chotikatam S, Kramomthong I and Angkanaporn K 2009 Effects of medium chain fatty acids, organic acids and fructo-oligosaccharide on cecal *Salmonella* Enteritidis colonization and intestinal parameters of broilers *THAI J VET MED* **39**(3) pp 245-258
- [38] Van Immerseel F, De Buck J, Boyen F, Bohez L, Pasmans F, Volf J, Sevcik M, Rychlik I, Haesebrouck F and Ducatelle R 2004 Medium-chain fatty acids decrease colonization and invasion through *hilA* suppression shortly after infection of chickens with *Salmonella enterica* serovar Enteritidis *Appl Environ Microbiol* **70**(6) pp 3582-3587
- [39] Zeiger K, Popp J, Becker A, Hankel J, Visscher C, Klein G and Meemken D 2017 Lauric acid as feed additive—An approach to reducing *Campylobacter* spp. in broiler meat *PLoS one* **12**(4) e0175693
- [40] Mathis G F, Van Dam J T P, Corujo F and Hofacre C L 2005 Effect of an organic acids and medium-chain fatty acids containing product in feed on the course of artificial Necrotic Enteritis infection in broiler chickens *In Proceedings of the 15th European Symposium on poultry nutrition, Balatonfüred, Hungary, 25-29 September, 2005* pp 372-374 World's Poultry Science Association (WPSA)
- [41] Del Alamo A G, De Los Mozos J, Van Dam J T P and De Ayala P P 2007 The use of short and medium chain fatty acids as an alternative to antibiotic growth promoters in broilers infected

- with malabsorption syndrome. In *Proceedings of the 16th European Symposium on Poultry Nutrition Strasbourg France* pp 317-320
- [42] Lipiński K, Mazur M, Makowski Z, Makowska A, Antoszkiewicz Z and Kaliniewicz J 2016 The effectiveness of the preparation medium-chain fatty acids (MCFA) and a herbal product on the growth performance of turkeys *Pol J Natur Sci* **31**(1) pp 47-57
- [43] Zeitz J O, Fennhoff J, Kluge H, Stangl G I and Eder K 2015 Effects of dietary fats rich in lauric and myristic acid on performance, intestinal morphology, gut microbes, and meat quality in broilers *Poult Sci* **94**(10) pp 2404-2413
- [44] Baltić B, Marković R, Šefer D, Glišić M, Hermans D and De Laet M 2016 The effect of adding a mixture of medium chain fatty acid-“aromabiotic” in the diet on broiler performance *Krmiva* **57**(2) pp 57-62