Postprint: Effects of Dietary Nutrients on Abdominal Fat Deposition in Waterfowl

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Abstract

Abdominal fat constitutes an important form of energy storage in waterfowl, and its deposition exerts significant influence on waterfowl product quality. Dietary nutrients can regulate waterfowl abdominal fat deposition through direct or indirect pathways by affecting blood biochemical indices, activities of lipid metabolism enzymes, and their expression levels. This review examines the effects and mechanisms of energy, protein, dietary fiber, fat, vitamins, and other nutrients on waterfowl abdominal fat deposition, aiming to provide a theoretical basis for nutritional regulation of abdominal fat in waterfowl.

Full Text

Review of Effects of Dietary Nutrients on Abdominal Fat Deposition in Waterfowls

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Abstract: Abdominal fat serves as a crucial form of energy storage in waterfowl and significantly influences product quality. Dietary nutrients regulate abdominal fat deposition in waterfowl by directly or indirectly affecting blood biochemical parameters, lipid metabolism enzyme activities, and their expression levels. This review synthesizes current research on how dietary energy, protein, fiber, fat, and vitamins affect abdominal fat deposition and its underlying mechanisms, aiming to provide a theoretical basis for nutritional regulation of abdominal fat in waterfowl.

Keywords: nutrients; waterfowl; abdominal fat deposition; regulation

To meet production and consumer demands, early breeding programs prioritized market weight, growth rate, and feed efficiency, resulting in new breeds with superior growth and slaughter performance but increasingly excessive body and abdominal fat proportions. As vital energy substances and reserves, body and abdominal fat play essential roles in poultry growth, reproduction, and metabolism. However, excessive fat deposition adversely affects carcass quality, flavor, and meat processing/storage characteristics, reducing consumer acceptance. Moreover, since most of this fat is physiologically unnecessary for poultry, it wastes feed resources and diminishes production profitability.

Unlike mammals, poultry have limited capacity for direct fat synthesis, relying heavily on hepatic synthesis and intestinal uptake of exogenous fats. Consequently, manipulating fat metabolism through dietary nutrients has become a key strategy for regulating fat deposition. While research on chickens is extensive and well-established, studies on waterfowl remain limited and inconsistent. Waterfowl differ from chickens in possessing two fatty acid synthesis pathways: the pyruvate-malate cycle and the pentose phosphate cycle. Summarizing nutrient effects on waterfowl abdominal fat deposition is therefore crucial for advancing fat metabolism research. This review examines how nutrient types influence abdominal fat deposition, focusing on energy, protein, fiber, amino acids, fat, and vitamins, and preliminary analyzes regulatory mechanisms to provide references for improving waterfowl product quality.

1. Effects of Dietary Energy on Abdominal Fat Deposition in Waterfowls

Energy is among the most critical nutritional factors affecting poultry fat metabolism, regulating lipid metabolism through impacts on feed intake, feed utilization efficiency, and metabolic processes. Numerous studies demonstrate that increasing dietary energy levels significantly elevates abdominal fat percentage in ducks and geese. Wei et al. reported that high-energy diets increased hepatic lipase (HL) mRNA expression in Yangzhou geese, suggesting that when waterfowl consume excess energy, the body enhances triglyceride (TG) hydrolysis by upregulating HL and lipoprotein lipase (LPL) activities to prevent metabolic disorders or excessive hepatic fat accumulation.

Unlike chickens, waterfowl utilize both the pyruvate-malate pathway and the pentose phosphate cycle for fatty acid synthesis. The pentose phosphate cycle, also known as the hexose monophosphate shunt, is a major source of reduced nicotinamide adenine dinucleotide phosphate (NADPH), which is essential for lipid synthesis. NADPH concentration is controlled by malate dehydrogenase (MDH), glucose-6-phosphate dehydrogenase (G-6-PDH), and 6-phosphogluconate dehydrogenase (6-PGD). Dietary energy levels regulate hepatic fat synthesis by affecting these key enzymes, including MDH, G-6-PDH, 6-PGD, and fatty acid synthase (FAS), subsequently influencing abdominal fat deposition. Li' s research on chickens found that medium-energy diets produced higher abdominal fat percentages than low- or high-energy diets, suggesting a potential inflection point in the relationship between dietary energy and fat deposition. Whether this phenomenon occurs in waterfowl requires further investigation.

Energy source also differentially affects fat metabolism. As the primary energy substrate and precursor for fat synthesis, carbohydrates promote fat deposition more effectively than dietary fats. Volek et al. confirmed that carbohydrates activate the carbohydrate-insulin axis, upregulating lipogenic genes such as sterol regulatory element-binding protein 1C (SREBP-1C) and carbohydrate response element binding protein (ChREBP), which enhances downstream fatty acid synthesis enzymes like acetyl-CoA carboxylase (ACC) and FAS, thereby promoting fat synthesis. Insulin, a key lipogenic hormone, increases cellular glucose uptake and consequently fat deposition when plasma concentrations rise.

2.1. Protein

Dietary protein level in poultry feed affects not only production costs but also feed intake, daily gain, and carcass quality. Research shows that increasing dietary protein levels significantly reduces or trends toward reducing abdominal fat percentage in geese and ducks. This indicates that protein levels influence waterfowl fat metabolism through direct or indirect mechanisms. Since most body fat originates from hepatic synthesis rather than dietary intake, and fatty acid synthesis requires acetyl-CoA and NADPH through seven enzymatic reactions, dietary protein likely regulates abdominal fat metabolism by modulating the activity and expression of key rate-limiting enzymes FAS and ACC.

Yalcin et al. found that increasing dietary protein significantly decreased hepatic FAS activity and mRNA expression in broilers. Zhou also observed reduced ACC activity with higher protein levels in geese. These findings demonstrate direct involvement of dietary protein in waterfowl fat metabolism. Given that waterfowl possess both pyruvate-malate and pentose phosphate pathways for fatty acid synthesis, dietary protein regulates abdominal fat deposition by influencing enzyme activities and mRNA expression of ACC, FAS, and other lipid metabolism enzymes. Additionally, reduced feed intake and gross energy metabolic rate in high-protein groups, along with higher energy expenditure during protein metabolism, may contribute to decreased abdominal fat deposition.

2.2. Amino Acids

Amino acids have attracted considerable research attention due to their special roles in animal production. Current research on amino acid effects on poultry fat deposition primarily focuses on methionine, lysine, and arginine.

2.2.1. Methionine

Methionine is the first limiting amino acid in corn-soybean meal diets for poultry and serves as both a protein synthesis substrate and major methyl donor, playing crucial roles in animal growth and product formation. Studies show that increasing dietary methionine supplementation reduces abdominal fat deposition. Fan et al. also observed that abdominal fat percentage in meat geese decreased initially then increased with rising methionine levels. Dietary methionine regulates fat synthesis by reducing blood TG levels and FAS activity while increasing hormone-sensitive lipase (HSL) activity.

2.2.2. Lysine

As a limiting amino acid, lysine is vital for poultry growth and meat quality development. Attia found that lysine deficiency significantly increased abdominal fat in ducks, while supplementation reversed this effect. Lin et al. reported that a 0.85% lysine diet significantly reduced abdominal fat percentage. Lysine appears to promote fat metabolism and reduce deposition by decreasing blood TG levels and increasing serum triiodothyronine (T3) and thyroxine (T4) levels.

2.2.3. Arginine

Arginine is a multifunctional essential amino acid currently applied in poultry fat metabolism regulation. Wu et al. demonstrated that increasing dietary arginine reduced abdominal fat deposition in ducks. Fang et al. also observed a trend toward decreased abdominal fat percentage in meat ducks. Dietary arginine supplementation decreased MDH, G-6-PDH, and FAS activities while suppressing FAS mRNA expression, reducing fat synthesis capacity. Additionally, studies have found enhanced mRNA expression of carnitine palmitoyltransferase I (CPTI) and 3-hydroxyacyl-CoA dehydrogenase (3HADH), increasing fatty acid β-oxidation and reducing body fat deposition.

3. Effects of Dietary Fiber on Abdominal Fat Deposition in Waterfowls

Early research suggested waterfowl lacked cellulose-degrading enzymes and could not utilize fiber. However, mounting evidence shows that appropriate dietary fiber proportions benefit growth, reproduction, and digestive tract function. Compared to ducks, geese prefer forage, so more research exists on fiber' s effects on goose carcass quality. Studies indicate that fiber source influences abdominal fat percentage, with rice hulls, ryegrass, and wheat bran showing trends toward reduction, though effects are often non-significant.

Zhang et al. and Zhu et al. found that dietary alfalfa and rice hulls significantly reduced serum TG levels in geese. Serum TG serves as an important indicator of normal fat metabolism and correlates negatively with abdominal fat percentage. The TG-lowering effect of alfalfa and rice hulls suggests their fiber components may have lipid-lowering properties beneficial for fat metabolism. Shi et al. reported that alfalfa meal significantly reduced abdominal fat percentage in Sichuan white geese compared to peanut straw. Wu also found that high corn stalk addition significantly decreased abdominal fat percentage in Jilin white and Carlos geese. These findings demonstrate that fiber source and composition differentially affect abdominal fat deposition in waterfowl.

4. Effects of Dietary Fat on Abdominal Fat Deposition in Waterfowls

Dietary fat, encompassing animal and plant oils, is commonly added to poultry feed as a primary energy source. Its effects on waterfowl abdominal fat deposition primarily relate to fatty acid chain length, saturation degree, and double bond position.

4.1. Fat Types

Research shows that both fat type and proportion in feed affect abdominal fat deposition and fatty acid composition in poultry. Liu et al. found that fish oil, corn oil, and soybean oil significantly reduced abdominal fat deposition in Landes geese compared to lard. Yu et al. demonstrated that a dietary n-6/n-3 polyunsaturated fatty acid (PUFA) ratio of 6:1 produced significantly lower abdominal fat percentage than ratios of 9:1 or 12:1.

Different fat types vary in fatty acid composition, chain length, saturation, and double bond position, differentially affecting fat metabolism. Compared with highly saturated animal fats, unsaturated vegetable oils more effectively inhibit FAS activity and gene expression while enhancing CPTI and 3HADH activities, reducing fatty acid synthesis and increasing oxidation, thereby decreasing fat deposition. Long-chain unsaturated fatty acids suppress hepatic ACC mRNA expression more effectively than short-chain unsaturated fatty acids, but show no significant effect on adipose tissue ACC mRNA expression, demonstrating tissue-specific regulation of fat metabolism by PUFAs.

As essential fatty acids, n-3 and n-6 PUFAs have distinct physiological functions and different mechanisms for inhibiting fat synthesis in poultry. Compared with sunflower oil, flaxseed oil significantly increased cardiac 3HADH activity in broilers without affecting hepatic malic enzyme (ME) or G-6-PDH activities, suggesting that flaxseed oil reduces abdominal fat deposition by promoting fatty acid β-oxidation rather than inhibiting synthesis.

4.2. Conjugated Linoleic Acid (CLA)

CLA refers to a mixture of positional and geometric isomers of linoleic acid, commonly added as a functional nutritional supplement. Following Simon et al.' s discovery that dietary CLA significantly reduced subcutaneous fat deposition in chickens, numerous studies have investigated CLA' s effects on abdominal fat in poultry. Results consistently show that CLA supplementation significantly reduces abdominal fat compared to controls or soybean oil supplementation.

As an energy repartitioning agent, CLA affects abdominal fat deposition by altering energy metabolism and nutrient redistribution. Proposed mechanisms include: (1) acting on fat metabolism-related hormones such as growth hormone, epinephrine, and norepinephrine to antagonize insulin' s stimulatory effect on fat synthesis, inhibiting FAS activity and mRNA expression while increasing fat breakdown; (2) modulating enzyme activities and mRNA expression related to fat metabolism, such as increasing HSL activity while inhibiting FAS and LPL activities; (3) regulating transcription factors by suppressing mRNA expression of peroxisome proliferator-activated receptor γ (PPARγ), adipocyte fatty acid-binding protein (aP2), and adipocyte determination and differentiation factor 1 (ADD1) in subcutaneous fat; and (4) reducing metabolic rate and inhibiting preadipocyte proliferation and differentiation to decrease adipocyte size. These mechanisms require further validation.

5. Effects of Vitamins on Abdominal Fat Deposition in Waterfowls

Vitamins, as cofactors or coenzymes in biological reactions, regulate fat metabolism enzymes and affect fat deposition by influencing one-carbon unit metabolic pathways. As methyl donors, folate, vitamin B6, and choline indirectly enhance epinephrine secretion, reduce hepatic MDH activity, and regulate liver lipid metabolism, thereby decreasing abdominal fat percentage. However, vitamin B6 shows non-significant effects on abdominal fat percentage in Wulong geese, suggesting limitations of indirect regulatory pathways in waterfowl.

Vitamin A exhibits strong hormone-like activity, reducing fat deposition by regulating growth hormone secretion via retinoic acid-binding protein and by inhibiting acetyl-CoA gene expression and preadipocyte differentiation through its metabolite retinoic acid. Sun et al. suggested that vitamin A modulates thyroid and insulin secretion to reduce abdominal fat deposition, though specific effects in waterfowl require further investigation due to limited research.

Riboflavin, existing as flavin mononucleotide (FMN) and flavin adenine dinucleotide (FAD), serves as a cofactor for multiple enzymes in fat metabolism and has been extensively studied for its effects on fat deposition. Wang et al. and Tang demonstrated that riboflavin supplementation significantly reduced abdominal fat percentage in geese. As a cofactor, vitamin B2 enhances fat breakdown by preventing β-oxidation impairment and may inhibit abdominal fat deposition by reducing serum TG and free fatty acid levels in laying ducks.

6. Effects of Manganese and Chromium on Abdominal Fat Deposition in Waterfowls

Manganese is an essential trace element crucial for poultry fat metabolism, serving as a cofactor for arginine kinase and pyruvate carboxylase while activating various kinases, hydrolases, decarboxylases, and transferases. Zhang et al. found that dietary manganese supplementation at 120 mg/kg significantly reduced abdominal fat percentage in geese. Manganese supplementation also decreases leg muscle MDH and abdominal fat LPL activities while increasing abdominal fat HSL activity, reducing fat synthesis and enhancing breakdown.

Chromium, as the active component of glucose tolerance factor (GTF), enhances insulin levels and regulates blood cholesterol to participate in fat metabolism. Chromium deficiency reduces blood insulin, impairing glucose metabolism and subsequently disrupting fat metabolism. Supplementation enhances insulin levels, LPL and lecithin cholesterol acyltransferase (LCAT) activities, and increases high-density lipoprotein (HDL) synthesis, thereby enhancing fat metabolism. While Li and Liu showed that chromium picolinate significantly reduced abdominal fat percentage in ducks, Tang et al. found no significant effect, indicating that chromium efficacy depends on product source, supplementation timing, and experimental subjects.

Fat metabolism is a complex, multi-factorial, multi-pathway process influenced by numerous factors. Dietary nutrients participate directly as substrates in de novo fatty acid synthesis while indirectly regulating key enzyme activities and mRNA expression through hormonal modulation. Although waterfowl and chickens share some fat metabolic pathways, important differences exist. While chicken abdominal fat regulation is well-researched with clarified mechanisms, waterfowl studies remain limited. Therefore, large-scale investigations into waterfowl fat metabolism patterns and mechanisms represent current research priorities. With advancing molecular biology and bioinformatics, future research should focus on comprehensive regulatory technologies and molecular mechanisms, providing deeper theoretical support for nutritional regulation of abdominal fat deposition in waterfowl.

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Note: Figure translations are in progress. See original paper for figures.