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Nutritional Factors Affecting Abdominal Fat Deposition in Poultry: A Review

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ABSTRACT: The major goals of the poultry industry are to increase the carcass yield and to reduce carcass fatness, mainly the abdominal fat pad. The increase in poultry meat consumption has guided the selection process toward fast-growing broilers with a reduced feed conversion ratio. Intensive selection has led to great improvements in economic traits such as body weight gain, feed efficiency, and breast yield to meet the demands of consumers, but modern commercial chickens exhibit excessive fat accumulation in the abdomen area. However, dietary composition and feeding strategies may offer practical and efficient solutions for reducing body fat deposition in modern poultry strains. Thus, the regulation of lipid metabolism to reduce the abdominal fat content based on dietary composition and feeding strategy, as well as elucidating their effects on the key enzymes associated with lipid metabolism, could facilitate the production of lean meat and help to understand the fat-lowering effects of diet and different feeding strategies. (**Key Words:** Abdominal Fat Content, Lipogenesis, Lipolysis, Nutritional Factors, Poultry)

INTRODUCTION

In 1953, chicken producers required more than 70 days to rear chickens to a final body weight of 1.5 kg. By 2001, however, chicken producers could rear chickens to their final body weight of 2.5 kg in a fattening period of only 42 days (Havenstein et al., 2003; Flock et al., 2005). Chickens have been genetically improved for increased body weight gain, feed efficiency, growth rate, and breast muscle weight to meet the requirements of consumers (Wang et al., 2012). These selection processes have produced modern commercial chicken lines with a higher growth rate, breast meat yield and better feed conversion rates, and a higher body fat compared with unselected lines (Baéza and Le Bihan-Duval, 2013). However, the excessive fat in modern poultry strains has been one of the major problems facing the poultry industry (Zhou et al., 2006). For example, Choct et al. (2000) found that modern broiler strains contain 15% to 20% fat and >85% of this fat is not physiologically required for body function. In general, excessive fat deposition is an unfavorable trait for producers and consumers because it is considered to be wasted dietary energy and a waste product with low economic value, which also reduces the carcass yield and affects consumer acceptance (Emmerson, 1997). Laying hens also exhibit excessive fat accumulation, which negatively affects their reproductive performance (Xing et al., 2009).

In avian species, most fatty acids are synthesized in the liver and transported via low-density lipoproteins or chylomicrons for storage in adipose tissues as triglycerides (Hermier, 1997). The abdominal fat tissue is crucial in poultry because it grows faster compared with other fat tissues (Butterwith, 1989). The abdominal fat pad is a reliable parameter for judging total body fat content because it is linked directly to total body fat content in avian species (Becker et al., 1979; Thomas et al., 1983).

Nutritional factors can regulate body fat deposition. In general, it is accepted that inhibiting the absorption of dietary fat and fatty acid synthesis, and/or promoting fatty acid β-oxidation reduces abdominal fat deposition by decreasing the size and/or number of abdominal adipose cells (Figure 1). Thus, this review discusses the nutritional factors that affect the abdominal fat content and how these factors can regulate abdominal fat deposition in poultry in a beneficial manner.

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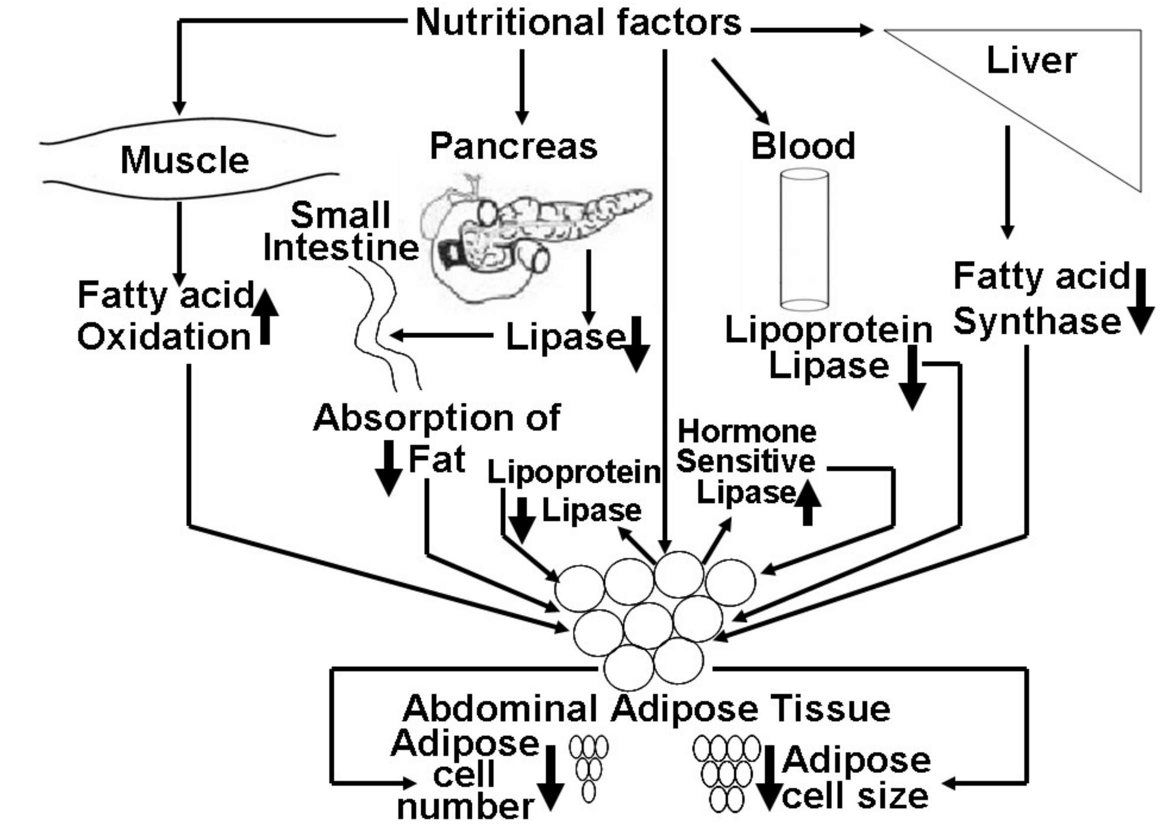

Figure 1. The mechanisms of nutritional factors that beneficially regulate abdominal fat deposition. Nutritional factors may: reduce fatty acid synthesis in the liver (the crucial site for fatty acid synthesis); suppress the secretion of pancreatic lipase, which reduces fat absorption; increase fatty acid β-oxidation in the muscles; inhibit the activity of lipoprotein lipase in the blood or abdominal adipose tissue; and/or enhance the activity of hormone-sensitive lipase in abdominal adipose tissue, which finally leads to a reduction in abdominal adipose tissue by decreasing the size and/or number of abdominal adipose cells. ↑, enhanced; ↓, inhibited.

DISCUSION

Nutrient levels on abdominal fat

Energy: In avian species, dietary energy level can be used to reduce the feed cost per unit of poultry product through its effects on feed intake and feed conversion, so it is one of the most important factors that can be modified to reduce body fat deposition. Kassim and Suwanpradit (1996) showed that reducing the energy level from 3,200 to 3,000 kcal/kg in broiler chickens from 21 to 42 days of age significantly reduced the abdominal fat percentage and total body fat deposition without any negative effects on the average daily gain, feed intake, or dressing percentage. Rabie and Szilagyi (1998) also found that the abdominal fat deposition was reduced significantly by decreasing dietary energy level from 3,227 to 3,059 kcal/kg in broilers from 18 to 53 days of age had no significant impact on the final live weight, carcass yield, or breast meat. Similar results were reported by Fan et al. (2008) who found that the breast and leg muscle percentages did not change whereas the abdominal fat weight relative to the live body weight was reduced significantly by decreasing dietary energy level from 2,900 to 2,700 kcal/kg in ducks from 14 to 42 days of age. Furthermore, Xie et al. (2010) showed that feeding ducklings from hatching to 21 day of age with a diet containing 2,747 kcal/kg led to a significant reduction in the abdominal fat content (percentage of live weight) without any significant reduction in the breast or leg meat compared with a diet containing 3,045 kcal/kg. Reducing dietary energy level leads to a reduction in total body fat deposition by decreasing the activity levels of a number of enzymes linked to hepatic lipogenesis, including nicotinamide adenine dinucleotide phosphate- malate dehydrogenase, glucose-6-phosphate dehydrogenase (G-6-PDH), 6-phosphogluconate dehydrogenase, and fatty acid synthase (FAS) in chickens (Tanaka et al., 1983). The FAS is a crucial enzyme in the *de novo* lipogenesis pathway in the liver of chickens. The ability of chickens to synthesize fatty acid deposits in the body is determined by the activity of FAS in the liver (Back et al., 1986). Therefore, the formulation of poultry diets to meet their energy requirements based on guidelines for specific strains is recommended to reduce body fat deposition, while increasing dietary energy content to improve feed conversion leads to the increased deposition of fat.

Protein: Protein is the most expensive component of poultry diets. Increasing dietary protein content improves the average daily gain, carcass yield, and carcass quality by increasing protein content while reducing body fat deposition. Kassim and Suwanpradit (1996) found that reducing dietary protein level from 23% to 20% crude protein (CP) during the starter phase, and from 20% to 18% CP during the finisher phase, led to a significant increase in the abdominal fat content. In a comparison of low-protein and normal-protein diets in broiler chickens, Collin et al. (2003) found that low-protein diets caused a significant increase in the abdominal fat content percentage. Yalçin et al. (2010) also found that feeding broiler chickens diets containing 19.2%, 16.6%, and 15.5% CP (low protein) led to an increase in total carcass fat deposition compared with chickens fed diets containing 22.9%, 19.9%, and 18.2% CP (the standard recommended by NRC [1994]) in the starter, grower, and finisher phases, respectively. Increasing dietary protein level in the diets of broiler chickens to 26.6%, 23.5%, and 20.7% in the starter, grower, and finisher phases led to a reduction in total carcass fat deposition compared with diets formulated according to NRC (1994) (Yalçin et al., 2010). Moreover, Jlali et al. (2012) found that increasing dietary CP level from 17% to 23% in fat and lean broiler chickens from 21 to 63 days of age caused a significant reduction in abdominal fat deposition. Therefore, dietary protein content must play a direct or indirect role in the regulation of lipid metabolism. However, Adams and Davis (2001) and Rosebrough et al. (2002) found that reducing dietary CP protein content upregulated malic enzyme mRNA expression and elevated the activity of malic enzyme in the liver of broilers compared with the control, whereas increasing dietary CP protein content downregulated malic enzyme mRNA expression and decreased the activity of malic enzyme in the liver of broilers compared with the controls. Choi et al. (2006) also showed that increasing dietary protein content caused a significant reduction in FAS mRNA expression in the livers of broiler chickens compared with the controls. Furthermore, Rosebrough et al. (2008; 2011) found that feeding broilers a diet containing a high CP level suppressed the mRNA expression of hepatic malic enzyme, acetyl coenzyme carboxylase (ACC), and FAS in a comparison of low-protein and high-protein diets. Therefore, dietary protein level affected body fat deposition directly. Thus, it is better to meet the protein requirements of birds to produce high quality meat with low fat deposition.

Amino acids: Methionine, the first-limiting amino acid in poultry diets, is important because of its effects on growth performance and also due to its effectiveness for producing lean meat (Takahashi et al., 1995). However, Corzo et al. (2006), Yao et al. (2006), and Zhan et al. (2006) reported significant increases in the abdominal fat percentage after feeding chickens methionine-deficient diets. By contrast, Xie et al. (2006) and Wang et al. (2010) found that increasing the methionine concentration in the diet caused a significant linear decrease in the abdominal fat content in their studies, which estimated the methionine requirements for White Pekin ducks from 21 to 48 days of age and for Yangzhou geese from 28 to 70 days of age. Andi (2012) reported that dietary L-methionine supplementation in broiler chickens led to a significant decline in body fat content. Changes in lipogenesis and/or lipolysis may be associated with the fat-lowering effect of dietary L-methionine. Takahashi and Akiba (1995) found that dietary L-methionine supplementation regulated the body fat content by reducing the activity of FAS (lipogenesis) and increasing the activity of hormone-sensitive lipase (HSL) (lipolysis).

In addition to its role as a limiting amino acid in poultry diets because of its effects on growth performance, lysine has a prominent role in meat quality by enhancing muscle pH, increasing protein deposition, and reducing the water-holding capacity (Berri et al., 2008; Tesseraud et al., 2009). The inclusion of lysine in poultry diets significantly enhances lean meat production. In 1990, Moran and Bilgili demonstrated a significant reduction in the carcass fatness by adding L-lysine. Grisoni et al. (1991) showed that increasing the lysine concentration in chicken diets reduced abdominal fat deposition. Attia (2003) found a significant increase in the abdominal fat percentage in meat-type ducks fed a lysine-deficient diet while the addition of lysine eliminated this effect. Moreover, Berri et al. (2008) and Nasr and Kheiri (2011) showed that dietary L-lysine supplementation lowered fat deposition in broiler chickens. Therefore, lysine can be added to poultry diets to promote lean meat production by reducing carcass fatness via lipogenesis inhibition (Grisoni et al., 1991).

Arginine is an essential amino acid that has multiple functions in poultry production, which has been implicated in reduced carcass fat deposition (Fouad et al., 2012). Corzo et al. (2003) indicated that the inclusion of arginine in broiler chicken diets at higher levels than NRC (1994) recommendations could reduce carcass fatness. In Japanese quails, Al–Daraji et al. (2011) found a significant reduction in the abdominal fat content as a percentage of body weight at 42 day of age after injections of 2.0% arginine at 0 days of incubation. In meat-type ducks, Wu et al. (2011) reported that providing 1.0% additional arginine above the NRC (1994) recommendations reduced the abdominal fat content and carcass fatness by decreasing the activities of malate dehydrogenase (MDH), G-6-PDH, and FAS (lipogenesis). Fouad et al. (2013) recently reported that dietary arginine inclusion at 0.25% reduced abdominal fat deposition by suppressing hepatic FAS mRNA expression and enhancing carnitine palmitoyl transferase I (CPT1) and L-3-hydroxyacyl-CoA dehydrogenase (3HADH) mRNA expression in the hearts of broiler chickens. CPT I and L3HOAD are recognized as the main enzymes involved with β-oxidation (Eaton, 2002). In avian species, therefore, dietary L-arginine supplementation inhibits hepatic FAS mRNA expression and improves CPT1 and 3HADH mRNA expression, which causes a reduction in the abdominal fat content by reducing the size of abdominal adipose cells (Wu et al., 2011; Fouad et al., 2013). At present, only three amino acids (methionine, lysine, and arginine) are known to beneficially regulate body fat deposition in poultry. Therefore, the inclusion of the optimal levels of these three amino acids in poultry diets should be ensured to avoid problems linked to fatness.

Minerals: Manganese (Mn) is a necessary trace mineral in poultry nutrition because of its central role in carbohydrate and lipid metabolism (Klimis-Tavantzis et al., 1983). Mn is also a powerful antioxidant that can be added to chicken diets to improve the meat shelf-life (Li et al., 2011). Moreover, Mn is effective for reducing the body fat content in broiler chickens. Sands and Smith (1999) first observed that adding Mn in the form of Mn proteinate at 240 mg/kg diet reduced the abdominal fat content as a percentage of the carcass weight. Lu et al. (2006) designed an experiment that used chickens to investigate the effects of different levels of inorganic Mn (0, 100, 200, 300, 400, and 500 mg/kg) on the abdominal fat content and to understand the effects of Mn on lipid metabolism. They reported that addition of Mn at 100 mg/kg to broiler diets that contained 23 mg Mn/kg significantly reduced the carcass fatness by downregulating the activity of lipoprotein lipase (LPL) in the abdominal fat. In avian species, it is well documented that fatty acids synthesized in the liver or those derived from the diet are transported to the adipose tissues via low-density lipoproteins or chylomicrons before storage in the adipose tissue, although only free fatty acids can pass through the adipocyte membranes so LPL hydrolyzes the triglycerides of chylomicrons and low-density lipoproteins to produce free fatty acids and glycerols, which are esterified into triglycerides in adipose tissues (Hermier, 1997). Therefore, LPL is necessary for the uptake of fatty acids by adipose tissues. It is well known that the bioavailability of organic minerals is higher compared with inorganic minerals. Thus, Lu et al. (2007) conducted an experiment to compare the effect of Mn sulphate (inorganic Mn) and Mn amino acid (organic Mn) on abdominal fat deposition. They found that the Mn source (organic or inorganic) did not affect fat deposition, whereas the concentration of Mn in the diet had a significant effect on the body fat content, i.e., diets supplemented with 100 mg Mn from organic or inorganic sources reduced body fat deposition by decreasing the activity of LPL and elevating the activity of HSL in the abdominal fat.

Fat types on abdominal fat

Fats and oils are used in poultry diet formulations to enhance the palatability of the diet, the absorption of fat-soluble vitamins, and to regulate the passage rate of the digesta in the gastrointestinal tract. They are also the most concentrated sources of energy (Baião and Lara, 2005). In avian species, the amount of fat that accumulates in the body depends on the available plasma lipid substrate, which originates from the diet or *de novo* lipogenesis in the liver (Hermier, 1997). Therefore, the sources of lipids in poultry diets may affect their total body fat deposition. Sanz et al. (1999; 2000a) observed that a diet containing tallow or lard (saturated fat) achieved the same growth performance as a diet that contained sunflower oil (unsaturated fat), whereas the abdominal fat content was significantly lower in the chickens fed diets containing sunflower oil. Experimental evidence indicated that dietary inclusion of sunflower oil was effective for reducing total body fat deposition compared with a diet containing tallow, but this raised the question of why the inclusion of unsaturated fats in the diets of broiler chickens led to a lower accumulation of body fat compared with the inclusion of saturated fats. However, Sanz et al. (2000b) found that the inclusion of sunflower oil in the diet of broilers led to a significant reduction in the abdominal fat percentage by inhibiting the activity FAS in the liver and enhancing the activities of CPT I and L3HOAD in the heart compared with the inclusion of tallow in the diet. Therefore, unsaturated fats reduce abdominal fat deposition and total body fat via this mechanism, in contrast to saturated fats. However, the next question was whether all unsaturated fats reduce abdominal fat deposition in broiler chickens. Therefore, Crespo and Esteve-Garcia (2001; 2002a) fed chickens diets supplemented with tallow (a rich source of saturated fatty acids), olive oil (a rich source of monounsaturated fatty acids), sunflower oil (a rich source of n-6 type polyunsaturated fatty acids), and linseed oil (a rich source of n-3 type polyunsaturated fatty acids). They reported that chickens fed diets supplemented with sunflower or linseed oils had a significant reduced in abdominal fat percentage and other fat depots, including mesenteric and neck fat, compared with chickens fed diets supplemented with tallow or olive oil. According to the results of Sanz et al. (2000b), the inclusion of sunflower oil in the diets of broilers promoted fatty acid oxidation and depressed fatty acid synthesis, so the abdominal fat percentage was decreased significantly. Linseed oil is a source of n-3 type polyunsaturated fatty acids while sunflower oil contains n-6 type polyunsaturated fatty acids. Thus, linseed oil could have reduced total body fat via the same mechanism as sunflower oil or other mechanisms. However, Crespo and

Esteve-Garcia (2002b) found that inclusion of linseed oil in the diets of broilers led to a significant reduction in the abdominal fat percentage and a significant increase in fatty acid synthesis compared with tallow or sunflower oil, so linseed oil may reduce the abdominal fat percentage by elevating fatty acid β-oxidation. A similar result was reported by Newman et al. (2002) who found that, compared with the addition of tallow, the addition of sunflower or fish oil to the diets of broilers from 21 to 56 days of age reduced abdominal fat deposition, increased the consumption of oxygen, and decreased the rate of oxygen consumption relative to the rate of carbon dioxide production, which showed that polyunsaturated fatty acids activate fatty acid β-oxidation. Furthermore, Ferrini et al. (2010) reported that, compared with those fed diets containing tallow, the activity of L3HOAD increased significantly whereas the activities of MDH and G-6-PDH (lipogenic enzymes) did not change in chickens fed diets containing linseed oil. This showed that linseed oil reduces abdominal fat deposition by promoting fatty acid β-oxidation, rather than suppressing fatty acid biosynthesis. Therefore, polyunsaturated fatty acids (n-3 and n-6 types) that have many benefits for human health (Simopoulos, 2000) can be used during poultry production to rear poultry products containing the optimal ratio of polyunsaturated fatty acids (n-3 and n-6) but also to reduce fat deposition in the abdomen area of poultry, which will enhance the producer returns and consumer health.

Conjugated linoleic acid on abdominal fat

The source of oils is not the only factor that can affect abdominal fat deposition in broilers. The structure of oil (fatty acid isomers) is one of the most important factors that can affect body fat deposition in broilers, as demonstrated by Simon et al. (2000). Their results indicated that the inclusion of conjugated linoleic acid (CLA) in chicken diets reduced the skin fat (one of the most important fat depots in poultry) compared with diets that lacked linoleic acid. CLA is a common name for the positional and geometric isomers of linoleic acid (9cis, 12cis octadecadienoic acid; 18:2n 6). A similar result was also reported by Badinga et al. (2003) who found that CLA depressed fat deposition in the livers of chickens in a comparison of CLA and corn oil (a rich source of linoleic acid). Moreover, Szymczyk et al. (2001) showed clearly that the inclusion of 1.5% CLA in broiler diets significantly reduced the abdominal fat content compared with the control diet (0% CLA). CLA can reduce abdominal fat deposition and lower total carcass fat deposition, as reported by Du and Ahn (2002). Zhang et al. (2009a) also supplemented 2.5% CLA in the diet of geese, which resulted in a significant reduction in the abdominal fat content compared with supplementation with the same amount of soybean oil, which is a rich source of linoleic acid. Zhang et al. (2007) and Zhou (2008) showed that CLA reduced body fat deposition in unimproved chicken strains (local strains), which have a low capacity for synthesizing lipids compared with improved strains (modern commercial chickens), as demonstrated by Cui et al. (2012). Zhang et al. (2007) demonstrated that a Beijingyou chicken diet containing 1.0% CLA led to a significant reduction in the abdominal fat content compared with a control diet that contained corn oil. The abdominal fat deposition was reduced significantly by adding 3.0% CLA to the diets of Yellow-feather broiler chickens compared with control diets containing 3.0% rapeseed oil as a rich source of linoleic acid (Zhou, 2008). According to these studies, CLA is a new tool that can be used to reduce fatness in modern broiler chickens, although the question remains why the inclusion of CLA in broiler diets caused a significant reduction in the abdominal fat content and total body fat deposition. Zhang et al. (2007) suggested that CLA reduces total body fat deposition in broilers by suppressing the activity of LPL in the plasma, while Zhou (2008) suggested that CLA reduced abdominal fat deposition in Yellow-feather broiler chickens (local Chinese strain) by downregulating peroxisome proliferator-activated receptor γ (PPARγ) mRNA expression in abdominal adipose tissue. Royan et al. (2011) confirmed the findings of Zhou (2008) by testing the inclusion of CLA in the diet of a commercial strain of broiler chickens (Ross 308), which caused a significant reduction in the abdominal fat percentage by reducing PPARγ mRNA expression in the abdominal adipose tissue. In avian species, PPARγ, which regulates lipid metabolism and adipocyte differentiation, is strongly associated with abdominal fat deposition (Sato et al., 2009; Wang et al., 2008; Xiong et al., 2010). In geese, Zhang et al. (2009a) suggested that CLA reduces the abdominal fat pad percentage by activating fatty acid oxidation via an increase in the activity of CPT I. In avian species, we can conclude that CLA reduces total body fat deposition directly by reducing the activity of LPL and downregulating PPARγ mRNA expression, and indirectly by elevating the activity of CPT I.

Various feed additives on abdominal fat

Betaine (glycine betaine or trimethylglycine) is highly concentrated in sugar beet and is classified as a byproduct of sugar production. It is considered to be an important source for methyl donors in farm animals (Virtanen, 1995). In White Pekin ducks, Wang et al. (2004) detected a reduction in the abdominal fat yield percentage after the inclusion of betaine in their diet. Zhan et al. (2006) also found that adding betaine to a methionine-deficient diet significantly reduced the fat deposition in broiler chickens. Su et al. (2009) reported that feeding Landes geese a diet supplemented with betaine caused a significant decrease in the abdominal fat compared with a nonsupplemented group. Furthermore, Xing et al. (2011) obtained the same result using broiler chickens fed a diet supplemented with betaine. The fat-lowering effect of betaine was elucidated by Zhan et al. (2006) and Xing et al. (2011) who showed that betaine lowered the body fat content in broilers by increasing the activity of HSL and reducing the activities of FAS and LPL in the abdominal fat.

L-Carnitine**,** which transports long-chain fatty acids across the inner mitichondrial membrane during β-oxidation (the first step in fatty acid oxidation: catabolism), is a water soluble zwitterionic compound, which is synthesized *in vivo* from lysine and methionine (Golzar Adabi et al., 2011). Because of its role in transporting long-chain fatty acids across the inner mitichondrial membrane during β-oxidation, it appears that L-carnitine may play an important role in reducing fat deposition in modern strains of broiler chickens. Rabie and Szilagyi (1998) reported that the inclusion of L-carnitine in broiler diets at 50 mg/kg for five weeks from 18 to 53 days of age caused a significant reduction in abdominal fat deposition. Arslan et al. (2003, 2004) found that feeding Turkish native ducks and geese the same diet supplemented with 200 or 100 mg L-carnitine in drinking water, respectively, led to a reduction in the abdominal fat percentage. Xu et al. (2003) showed that the abdominal fat expressed as a percentage of live weight was significantly reduced by the addition of 50 mg/kg L-carnitine to the diets of broiler chickens. Feeding female broiler breeders a diet supplemented with 25 mg/kg L-carnitine also reduced the carcass fatness of their progeny (Kidd et al., 2005). Therefore, dietary L-carnitine supplementation decreases abdominal fat deposition in meat-type poultry by reducing the activities of G-6-PDH, MDH (lipogenic enzymes), and LPL in the abdominal fat, as suggested by Xu et al. (2003).

Probiotics is a name given to live microorganisms that have a positive effect on animal health. Santoso et al. (1995) indicated that probiotics can be added to broiler diets to reduce body fat deposition and carcass cholesterol, which suggests that probiotics beneficially regulate lipid metabolism. To test the findings of Santoso et al. (1995), Kalavathy et al. (2003) investigated the effects of *Lactobacillus* cultures on the abdominal fat traits and lipid profiles of broiler chickens. They found that feeding chickens aged 14 to 42 days on diets supplemented with a mixture of 12 *Lactobacillus* strains at 0.1% significantly reduced the serum triglyceride concentration, with a concomitant decrease in abdominal fat traits. Homma and Shinohara (2004) also reported that the inclusion of probiotic *Bacillus cereus toyoi* in the diets of male quails from 27 to 55 days of age for four weeks significantly reduced abdominal fat accumulation. Kalavathy et al. (2006) found that *Lactobacillus* cultures reduced the abdominal fat traits and also improved the carcass quality by reducing carcass fatness. Similarly, Yamamoto et al. (2007) showed that dietary supplementation with *Aspergillus awamori*-fermented distillery by-product, at 1.0% significantly lowered abdominal fat deposition in broiler chickens. Cao et al. (2012) found that feeding broiler chickens a diet supplemented with *Aspergillus niger*-fermented *Ginkgo biloba* leaves at 0.5% and 1.0% in the starter and grower phases, respectively, significantly reduced abdominal fat accumulation. Thus, Saleh et al. (2012) examined the effects of including *Aspergillus awamori* at 0.05% or 0.20% on abdominal fat deposition. They found that the inclusion of *Aspergillus awamori* at 0.05% was sufficient to induce a significant reduction in the abdominal fat percentage. In a comparison of the effects of *Aspergillus awamori* and *Aspergillus niger* on abdominal fat traits in chickens, Saleh et al. (2011) showed that *Aspergillus awamori* at 0.01% or *Aspergillus niger* at 0.05% in the diet significantly reduced abdominal fat deposition. Therefore, the deposition of poultry abdominal fat could be reduced by supplementing probiotics in the diet because probiotics inhibit lipid biosynthesis (Santoso et al., 1995; Yamamoto et al., 2007) and promote fatty acid catabolism (Homma and Shinohara, 2004).

Polysavone is extracted from alfalfa and contains 18.63% polysaccharides, 5.58% triterpenoid saponins, and 5.89% flavonoids. It has been implicated in the reduction of poultry abdominal fat deposition by downregulating the activity levels of ACC and FAS (Dong et al., 2007; Deng et al., 2012).

Green tea contains high levels of polyphenols, which are thought to be useful as antiobesity compounds. It has been reported that the inclusion of green tea powder at 0.5% in the diets of broiler chickens significantly reduced abdominal fat traits by inhibiting hepatic lipogenesis (Biswas and Wakit, 2001).

Chitooligosaccharide, which has a low molecular weight, low viscosity, and acceptable solubility, is an oligosaccharide that can be added to the diets of broiler chickens at 0.4% to reduce abdominal fat deposition (Zhou et al., 2009). Chitooligosaccharide lowered body fat deposition by reducing lipid uptake via the suppression of the enzyme activity of pancreatic lipase (Kang et al., 2012).

Chitosan is a linear polysaccharide with low viscosity that is produced commercially from crab and shrimp shell waste. Chitosan has been used to reduce the fat content in the abdominal area of poultry by inhibiting the absorption of dietary fat via the suppression of lipase activity due to a reduction in the levels of bile acids (Kobayashi and Itoh, 1991; Kobayashi et al., 2002).

Ginseng, the root of *Panax ginseng* C. A. Meyer, is a well-known traditional herbal drug in East Asian countries, which has been used to treat several heart diseases and metabolic diseases (Yan et al., 2011a). Ginseng has many bioactive components such as saponins that inhibit lipogenesis in chickens (Qureshi et al., 1983). The blood triglyceride concentration was significantly reduced by adding wild ginseng adventitious root to the diets of laying hens (Yan et al., 2011a). This reduced the availability of blood triglyceride for transport and deposition in the abdominal areas of poultry. Yan et al. (2011b) showed that the inclusion of wild ginseng adventitious root meal at 0.3% in the diets of broiler chickens led to a significant reduction in abdominal fat deposition.

Thyme (*Thymus vulgaris*) is a medicinal herb that can be used as a natural alternative to antibiotics in poultry production (Khan et al., 2012) but it also has inhibitory effects on abdominal fat traits in broiler chickens (Al-Kassie, 2009; Abdulkarimi et al., 2011). Al-Kassie (2009) showed that adding 200 ppm thyme oil to the diets of broiler chickens during the fatting period (42 days) caused a significant reduction in the abdominal fat percentage compared with the control diet. Abdulkarimi et al. (2011) reported that adding 0.6% thyme extract to drinking water significantly reduced the accumulation of fat in the abdominal areas of broiler chickens. The reduction in the abdominal fat traits caused by thyme supplementation may have been attributable to the saponins in thyme (Abdulkarimi et al., 2011), which have inhibitory effects on lipogenesis (Qureshi et al., 1983).

Dihydropyridine, which has been approved as an antioxidant in poultry feed (Bakutis and Bukis, 1984; Zou et al., 2007; Niu et al., 2010; 2011), can reduce abdominal fat traits in laying hens, broiler chickens, and broiler breeder hens (Zou et al., 2007; Niu et al., 2010; 2011). Zou et al. (2007) found that feeding laying hens a diet supplemented with 300 mg/kg dihydropyridine for three months significantly reduced abdominal fat deposition by increasing the activity of HSL in the abdominal fat. Niu et al. (2010) found that adding 100 mg/kg dihydropyridine to broiler diets from one to 42 days of age was sufficient to suppress the activities of LPL in abdominal fat, as well as MDH and G-6-PDH in the liver, and to increase the levels of HSL in abdominal fat, thereby reducing the abdominal fat percentage. In broiler breeder hens, Niu et al. (2011) showed that the inclusion of dihydropyridine at 200 mg/kg in the diet was sufficient to reduce the accumulation of fat in the abdomen area by simulating the activity of HSL in the abdominal fat.

Alpha lipoic acid is a naturally occurring compound that has beneficial effects on poultry production. Experimental evidence in poultry suggests that dietary alpha lipoic acid supplementation alleviates oxidative stress, enhances the antioxidant capacity, improves meat quality, and lowers body fat deposition (Zhang et al., 2009b; Chen et al., 2011; Halici et al., 2012; El-Senousey et al., 2013). Zhang et al. (2009b) reported that diets supplemented with 900 mg/kg alpha lipoic acid from one to 42 days of age reduced the abdominal fat content in broiler chickens. A similar result was reported by El-Senousey et al. (2013) who fed broiler chickens from 21 to 42 days of age using a diet supplemented with 800 mg/kg alpha lipoic acid. The fat-lowering effect of alpha lipoic acid may have been due to increased fatty acid β-oxidation (Shen et al., 2007) and/or elevated HSL activity (Fernandez-Galilea et al., 2012).

Feed restriction on abdominal fat

Limiting the feed intake in avian species using various methods (quantitative or qualitative feed restriction) has successfully addressed many problems that affect poultry farms due to intensive selection, *e.g.*, fatness. Plavnik and Hurwitz (1985; 1991) showed that quantitative feed restriction was effective for reducing the abdominal fat content compared with full feeding. Santoso et al. (1993) also showed that quantitative feed restriction for 10 days (beginning on the first day in the second week of age for female broiler chickens) led to a significant reduction in the abdominal fat percentage and total body fat deposition. It is well known that female broiler chickens tend to deposit more fat than male broiler chickens. Moreover, Tan and Othani (2000) demonstrated that quantitative (50% of full feed) or qualitative (diet diluted with 50% rice hulls) feed restriction in White Pekin ducks for six days starting at eight days of age caused a significant reduction in body fat deposition at the end of the fatting period compared with full feeding. Rezaei et al. (2010) and Wu et al. (2012) confirmed that qualitative feed restriction in modern broiler chickens and meat-type ducks reduced body fat deposition. Rezaei et al. (2010) found that the inclusion of rice hulls in the diet of broiler chickens at a level of 20% for five days starting at 16 days of age significantly reduced the abdominal fat and total body fat deposition. Wu et al. (2012) showed that meat-type ducks fed a diet diluted with 40% rice hulls for seven days starting at eight days of age led to a significant improvement in the meat quality by reducing the fat depots, including abdominal fat and skin fat. In broiler chickens, Santoso (2001) found there was a significant depression in the abdominal fat percentage and in the accumulation of fat in the body at market weight by limiting the feed intake to 25% of the *ad libitum* level for nine days starting on the first day of the second week of age, in a comparison of different levels of feed restriction and full feed. Similarly, Chen et al. (2012) showed that feeding chickens a diet containing 70% of their energy requirements by limiting the feed consumption to 80% of the full feed significantly reduced the abdominal fat pad and the thickness of subcutaneous fat compared with the control.

Restricted feed consumption lowered the body fat content in meat-type chickens and ducks and also reduced

Table 1. Some additives used in poultry diets to reduce the abdominal fat content

Item	Amount (g/kg feed)	Mechanism[1]	Source
L-Arginine	2.5 (Broiler chickens) 10.0 (Ducks)	Lipogenesis ↓ Lipolysis ↑	Fouad et al., 2013; Wu et al., 2011
L-Carnitine	0.05 (Broiler chickens)	Lipogenesis ↓ Lipotein lipase ↓	Xu et al., 2003
Probiotics	1.0 *Lactobacillus* strains, 0.1 *Aspergillus awamori*, or 0.5 *Aspergillus niger* (Broiler chickens)	Lipogenesis ↓	Kalavathy et al., 2003; Saleh et al., 2011;2012; Santoso et al., 1995; Yamamoto et al., 2007
Polysavone	0.6 (Broiler chickens)	Lipogenesis ↓	Dong et al., 2007; Deng et al., 2012
Green tea	5.0 (Broiler chickens)	Lipogenesis ↓	Biswas and Wakit, 2001
Chitooligosaccharide	4.0 (Broiler chickens)	Lipase ↓	Zhou et al., 2009; Kang et al., 2012
Chitosan	50 (Broiler chickens)	Lipase ↓	Kobayashi and Itoh, 1991; Kobayashi et al., 2002
Ginseng	3.0 (Broiler chickens)	Lipogenesis ↓	Yan et al., 2011b; Qureshi et al., 1983
Thyme	0.2 (Broiler chickens)	Lipogenesis ↓	Al-Kassie, 2009; Qureshi et al., 1983
Dihydropyridine	0.3 (Laying hens) 0.1 (Broiler chickens) 0.2 (Broiler breeder hens)	Lipolysis ↑ Lipogenesis ↓	Zou et al., 2007; Niu et al., 2010;2011
Alpha lipoic acid	0.8 (Broiler chickens)	Lipolysis ↑	El-Senousey et al., 2013; Fernandez-Galilea et al., 2012; Shen et al., 2007

[1] ↑, enhanced; ↓, inhibited.

fat accumulation in broiler breeders (Richards et al., 2003). Several studies have tested why feed restriction reduces the body fat content in poultry (Santoso et al., 1993; Tan and Othani, 2000; Yang et al., 2010; Wu et al., 2012). Santoso et al. (1993) suggested that quantitative feed restriction reduces fat deposition by inhibiting the activity of the rate-limiting enzyme during lipogenesis (ACC) in the livers of broiler chickens. Tan and Othani (2000) found that quantitative or qualitative feed restriction decreased the activities of the main lipogenic enzymes, including ACC and FAS, in the livers of White Pekin ducks. Wu et al. (2012) confirmed that feed restriction lowered the body fat content by decreasing the hepatic activity of MDH, G-6-PDH, and FAS enzymes. Santoso et al. (1993), Tan and Othani (2000), and Wu et al. (2012) confirmed the study of Zhong et al. (1995) who showed that feed restriction significantly reduced hepatic lipogenesis (in an *in vitro* study). Yang et al. (2010) suggested that feed restriction regulates body fat deposition to promote lean meat production by reducing fatty acid biosynthesis and elevating fatty acid β-oxidation. Therefore, feed restriction reduces fat deposition by inhibiting hepatic lipogenesis and elevating fatty acid oxidation. Zhong et al. (1995) found that early feed restriction significant reduced abdominal fat deposition because of a significant decrease in the number of abdominal adipose cells. Thus, the application of quantitative or qualitative feed restriction in commercial farms could be an effective method for reducing the level of undesirable fat in modern strains of poultry.

CONCLUSIONS

First, poultry diets should be formulated as recommended by the guidelines for specific strains to avoid the problems of fatness in poultry. Second, replacing saturated fatty acids with polyunsaturated fatty acids (n-3 and n-6) or CLA, applying feed restriction, or including additives (Table 1) in poultry diets can also help to reduce abdominal fat deposition. However, the fat-reducing effects of nutritional factors have not been fully elucidated. Thus, Figure 1 and Table 1 may be helpful for appreciating our current understanding of the mechanism (s) underlying the effects of nutritional factors that beneficially regulate abdominal fat deposition and to identify the studies required to elucidate the fat-reducing effects of nutritional factors in poultry.

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