Effects of Linoleic Acid on Growth Performance, Slaughter Performance, Meat Quality, and Nutrient Utilization in Meat Geese Aged 5-16 Weeks: Postprint

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Abstract

This experiment was conducted to investigate the effects of linoleic acid on growth performance, slaughter performance, meat quality, and nutrient utilization in meat geese aged 5-16 weeks, and to determine the optimal dietary linoleic acid level. A total of 360 five-week-old Wulong geese were randomly assigned to 6 groups, with 6 replicates per group and 10 geese per replicate (half male and half female). The dietary linoleic acid levels in the 6 groups (Groups I-VI, with Group I as the control) were 0.52%, 0.72%, 0.92%, 1.12%, 1.32%, and 1.52%, respectively. The experimental period lasted 12 weeks. The results showed: 1) Groups III and IV exhibited significantly or highly significantly higher body weight and average daily gain compared with the control group (P<0.05 or P<0.01), and significantly lower feed/gain ratio (F/G) (P<0.05). 2) Analysis using the unrelated comparison method revealed that the highest slaughter rate was achieved at a dietary linoleic acid level of 1.09%. Groups IV and V showed significantly higher breast muscle rate than the control group (P<0.05), while Groups III and IV had significantly or highly significantly lower abdominal fat rate than the control group (P<0.05 or P<0.01). 3) Groups III-VI displayed significantly or highly significantly higher muscle lightness (L*) values than the control group (P<0.05 or P<0.01); Group IV presented highly significantly higher muscle redness (a*) value than the control group (P<0.01),* and significantly or highly significantly lower water loss rate and shear force (P<0.05 or P<0.01); Groups IV-VI exhibited significantly higher pH than the control group (P<0.05). 4) Group IV demonstrated highly significantly higher utilization rates of crude protein, crude fat, and calcium than the control group (P<0.01). Groups II-VI showed significantly higher phosphorus utilization rate than the control group (P<0.05). Groups III-VI had significantly or highly significantly lower fecal nitrogen excretion than the control group (P<0.01), and significantly or highly significantly higher deposited nitrogen and nitrogen utilization rate than the control group (P<0.05 or P<0.01). These results indicate that appropriate dietary linoleic acid levels can improve growth performance, slaughter performance, meat quality, and nutrient utilization, and reduce abdominal fat rate in meat geese aged 5-16 weeks. The optimal dietary linoleic acid level for meat geese aged 5-16 weeks is 0.92%-1.12%.

Full Text

Effects of Linoleic Acid on Growth Performance, Slaughter Performance, Meat Quality and Nutrient Utilization in Meat Geese Aged 5 to 16 Weeks

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Abstract: This experiment was conducted to investigate the effects of dietary linoleic acid levels on growth performance, slaughter performance, meat quality, and nutrient utilization in meat geese aged 5 to 16 weeks, and to determine the optimal dietary linoleic acid level. A total of 360 five-week-old Wulong geese were randomly allocated into 6 groups with 6 replicates per group and 10 geese per replicate (half male and half female). The six groups (Groups – , with Group as the control) were fed diets containing 0.52%, 0.72%, 0.92%, 1.12%, 1.32%, and 1.52% linoleic acid, respectively. The experiment lasted for 12 weeks. The results showed: 1) Body weight and average daily gain (ADG) in Groups and were significantly or extremely significantly higher than those in the control group (P<0.05 or P<0.01), while the feed-to-gain ratio (F/G) was significantly lower (P<0.05). 2) Using orthogonal comparison analysis, the highest dressing percentage was achieved at a dietary linoleic acid level of 1.09%. The breast muscle percentage in Groups and was significantly higher than that in the control group (P<0.05), while the abdominal fat percentage in Groups and was significantly or extremely significantly lower (P<0.05 or P<0.01). 3) The lightness (L*) value of muscle in Groups – was significantly or extremely significantly higher than that in the control group (P<0.05 or P<0.01). The redness (a*) value in Group was extremely significantly higher than that in the control group (P<0.01), while water loss rate and shear force were significantly or extremely significantly lower (P<0.05 or P<0.01). The pH value in Groups – was significantly higher than that in the control group (P<0.05). 4) The utilization rates of crude protein, ether extract, and calcium in Group were extremely significantly higher than those in the control group (P<0.01). Phosphorus utilization in Groups – was significantly higher than that in the control group (P<0.05). Fecal nitrogen excretion in Groups – was significantly or extremely significantly lower than that in the control group (P<0.01), while deposited nitrogen and nitrogen utilization were significantly or extremely significantly higher (P<0.05 or P<0.01). These results indicate that appropriate dietary linoleic acid levels can improve growth performance, slaughter performance, meat quality, and nutrient utilization while reducing abdominal fat percentage in 5-16 week-old meat geese. The optimal dietary linoleic acid level for meat geese aged 5–16 weeks is 0.92%–1.12%.

Keywords: linoleic acid; geese; growth performance; slaughter performance; meat quality; nutrient utilization

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Linoleic acid belongs to the n-6 series of polyunsaturated fatty acids (PUFA). As it plays a crucial protective role in normal physiological functions and health, and must be provided through the diet, it is classified as an essential fatty acid—the first to be recognized and one of the most important PUFAs [1]. As the original member of the n-6 PUFA family, linoleic acid can be converted into various PUFAs that perform vital physiological functions. The n-6 series PUFAs are most important for higher mammals and poultry, though in animal nutrition, only linoleic acid is typically considered for most animals [2]. Balnave [3] found that linoleic acid deficiency in chicks resulted in growth retardation, increased water intake, reduced disease resistance, elevated liver fat content with enlarged liver volume, increased eicosatrienoic acid content in many tissues, and decreased linoleic and arachidonic acid contents. In roosters, testes became smaller and secondary sexual characteristics developed slowly. Watkins [4] suggested that linoleic acid deficiency could cause reproductive disorders in poultry and increased susceptibility to infectious diseases, possibly related to increased harmful eicosanoids. Menge [5] fed laying hens a diet based on glucose and soy protein concentrate for 32 weeks and found that hens achieved maximum egg production when linoleic acid content was 2%. Wang Baowei et al. [6] added safflower oil rich in linoleic acid at 2%, 4%, and 6% to a basal diet, which improved the physiological status and laying performance of hens. To date, research on dietary linoleic acid supplementation in poultry has mainly focused on laying performance in hens, with few reports on linoleic acid requirements for geese. Consequently, NRC (1994) [7] remains the most authoritative reference standard for linoleic acid supplementation in goose diets. NRC (1994) [7] recommends a linoleic acid requirement of 1% for geese aged 1–4 weeks and 0.8% for geese older than 4 weeks. The linoleic acid requirement proposed by NRC (1994) [7] approximates the minimum level needed to prevent typical clinical deficiency symptoms. While the recommended level may allow geese to appear normal, growth performance may not be optimal, especially under commercial production conditions. Whether the linoleic acid requirement provided by NRC (1994) [7] meets the growth needs of geese remains unknown, as relevant databases are still lacking and require further research. Therefore, this study used 5–16 week-old Wulong geese (Huoyan geese) as experimental subjects to investigate the effects of different dietary linoleic acid levels on growth performance, slaughter performance, meat quality, and nutrient utilization, aiming to determine the appropriate dietary linoleic acid level for 5-16 week-old Wulong geese and provide theoretical support for China's meat goose nutrition standard database.

1.1 Experimental Animals and Design

A total of 360 healthy five-week-old Wulong geese with uniform body weight were randomly divided into 6 groups using a random allocation numbering method, with 6 replicates per group and 10 geese per replicate (half male and half female). Group served as the control group and was fed a low-linoleic acid diet (0.52% linoleic acid), while Groups – were fed diets with linoleic acid levels of 0.72%, 0.92%, 1.12%, 1.32%, and 1.52%, respectively. The experiment lasted for 12 weeks. Experimental geese were provided by the Wulong Goose Original Breed Breeding Base in Laiyang City, Shandong Province.

1.2 Experimental Diets

The basal diet composition and nutrient levels were designed according to NRC (1994) poultry nutrient requirements. A wheat-soybean meal basal diet was used, and the linoleic acid content in feed ingredients was measured to formulate experimental diets based on actual values. The basal diet contained 0.52% linoleic acid, and dietary linoleic acid content was adjusted using corn oil, tallow, and palm oil at 0.2% increments. The composition and nutrient levels of experimental diets are shown in Table 1 .

1.3 Management

Before the experiment, the goose house was thoroughly disinfected. Throughout the experiment, geese were raised indoors on deep litter in separate pens. They had free access to water and feed, with frequent small additions, and their growth status was monitored closely.

1.4 Measurements

Growth Performance: At the end of 16 weeks, geese were fasted and weighed by replicate to calculate average daily gain (ADG) from 5 to 16 weeks. Daily feed consumption was recorded to calculate average daily feed intake (ADFI) and feed-to-gain ratio (F/G). Mortality and culling rates were recorded daily.

Slaughter Performance: At the end of 16 weeks, after fasting and wing vein blood collection, 72 geese (2 per replicate) were slaughtered. After 12 hours of pre-slaughter fasting, dressing weight, semi-eviscerated weight, fully eviscerated weight, abdominal fat weight, breast muscle weight, and leg muscle weight were measured according to *Poultry Production Performance Terminology and Measurement Methods* (NY/T 823-2004). Dressing percentage, eviscerated percentage, semi-eviscerated percentage, abdominal fat percentage, leg muscle percentage, and breast muscle percentage were calculated.

Meat Quality: At the end of 16 weeks, 2 geese were randomly selected from each replicate (72 geese total). After wing vein blood collection and slaughter, meat quality was measured according to *Meat Products Testing Standards* (GB/T 9695.19-2008). The entire breast muscle was removed from the sternum, and the anterior pectoralis major was sampled. Lightness (L*), redness (a*), and yellowness (b*) values were measured using a Japanese automatic colorimeter. Shear force was measured using a texture analyzer (TA-XT PLUS). pH was measured using a portable pH meter (HANHA-HI9025). Drip loss was measured using the bag method, and water loss rate was measured using a pressure meter.

Nutrient Utilization: At 14 weeks, 6 geese (half male and half female) were randomly selected from each group and moved to metabolic cages (Patent No.: 200720177297). The trial consisted of a 4-day preliminary period, 1-day fasting period, and 3-day formal period, with free access to water and 100 g of experimental diet daily. Excreta were continuously collected for 4 days using the total collection method. Fecal collection trays were placed under metabolic cages and collected at fixed times daily, with nitrogen fixation by hydrochloric acid, then mixed and sampled.

Feed samples to be tested were ground to 40 mm and stored at low temperature after drying. Fecal samples were dried in an oven at 65–75 °C, rehydrated for 24 h under natural conditions to prepare air-dried samples, then ground using a small universal grinder. Gross energy (GE) was determined using the bomb calorimetry method; crude protein (CP) content was detected using FOSS TECATOR QUALITY ASSURANCE equipment; calcium (Ca) content was determined using the potassium permanganate method; phosphorus (P) content was determined using a BioSpec-1610 nucleic acid protein analyzer with colorimetry; crude fiber (CF), neutral detergent fiber (NDF), and acid detergent fiber (ADF) contents were determined using an ANKOM2000 Fiber Analyzer (NY14450) from ANKOM Company; ether extract (EE) content was determined using the ether extraction method. Nutrient utilization calculation formulas followed reference [8].

1.5 Statistical Analysis

Data were analyzed using one-way ANOVA with LSD multiple comparisons in SPSS 17.0 software. Results were expressed as "mean ± standard deviation." Orthogonal comparison was used to analyze linear or curvilinear responses of various indices to dietary linoleic acid levels, and curve fitting was employed to determine the optimal dietary linoleic acid level for 5–16 week-old meat geese. $P<0.05$ and $P<0.01$ were considered significant and extremely significant, respectively.

2.1 Effects of Dietary Linoleic Acid Level on Growth Performance of Geese

As shown in Table 2 , body weight and ADG in Group were significantly higher than those in the control group ($P<0.05$), while Group showed extremely significant differences ($P<0.01$). The F/G in Groups and was significantly lower than that in the control group ($P<0.05$), with no significant difference between Groups and ($P>0.05$). No significant differences were observed in ADFI or mortality rate among groups ($P>0.05$).

Quadratic curve fitting and regression analysis revealed that the curve fitting between growth performance and dietary linoleic acid level was not significant ($P>0.05$). These results indicate that a dietary linoleic acid level of 1.12% yielded maximum body weight and ADG, while levels of 0.92%-1.12% resulted in the lowest F/G. From a comprehensive benefit perspective, the recommended dietary linoleic acid level for optimal growth performance is 0.92%-1.12%.

2.2 Effects of Dietary Linoleic Acid Level on Slaughter Performance of Geese

As shown in Table 3 , all linoleic acid supplementation groups had higher dressing percentages than the control group during weeks 5-16, with Groups and showing extremely significant differences ($P<0.01$) and Groups , , and showing significant differences ($P<0.05$). Breast muscle percentage in Groups and was significantly higher than that in the control group ($P<0.05$). Abdominal fat percentage in Groups and was significantly or extremely significantly lower than that in the control group ($P<0.05$ or $P<0.01$).

Since no significant difference in dressing percentage was observed between Groups and ($P>0.05$), a quadratic curve was fitted using dressing percentage (Y) from Groups - against dietary linoleic acid level (X), establishing the regression equation: Y=68.054+36.386X-16.613X2 (R2=0.765, PQ=0.001). This equation indicates that the highest dressing percentage was achieved at a dietary linoleic acid level of 1.09%. From a comprehensive benefit perspective, the recommended dietary linoleic acid level for optimal slaughter performance is 1.09%-1.12%.

2.3 Effects of Dietary Linoleic Acid Level on Meat Quality of Geese

As shown in Table 4 , dietary linoleic acid level significantly or extremely significantly affected muscle L* value, a* value, shear force, pH, and water loss rate ($P<0.05$ or $P<0.01$). The L* value in Groups and was significantly higher than that in the control group ($P<0.05$), while Groups and showed extremely significant differences ($P<0.01$). The a* value in Groups , , and was significantly higher than that in the control group ($P<0.05$), and Group showed an extremely significant difference ($P<0.01$). Shear force in Group was significantly lower than that in the control group ($P<0.05$). The pH value in Groups - was significantly higher than that in the control group ($P<0.05$).

Water loss rate in Groups , , and was significantly lower than that in the control group (P<0.05), and Group showed an extremely significant difference (P<0.01). Dietary linoleic acid level had no significant effect on b* value (P>0.05). These results demonstrate that dietary linoleic acid supplementation can improve goose meat quality.

2.4 Effects of Dietary Linoleic Acid Level on Nutrient and Energy Utilization of Geese

As shown in Table 5 , dietary linoleic acid level significantly or extremely significantly affected the utilization rates of CP, EE, calcium, and phosphorus (P<0.05 or P<0.01). The utilization rates of CP, EE, and calcium in Group were extremely significantly higher than those in the control group (P<0.01). Phosphorus utilization in Groups – was significantly higher than that in the control group (P<0.05). Dietary linoleic acid level had no significant effect on the utilization rates of CF, NDF, or ADF (P>0.05).

As shown in Table 6 , fecal nitrogen excretion in Groups – was significantly or extremely significantly lower than that in the control group (P<0.05 or P<0.01), while deposited nitrogen and nitrogen utilization were significantly or extremely significantly higher (P<0.05 or P<0.01). Dietary linoleic acid level had no significant effect on nitrogen intake (P>0.05).

As shown in Table 7 , no significant differences were observed among groups in GE intake, fecal GE excretion, endogenous energy, apparent metabolizable energy, true metabolizable energy, or GE utilization (P>0.05).

3.1 Effects of Dietary Linoleic Acid Level on Growth Performance of Geese

Linoleic acid is the earliest recognized essential fatty acid and an important unsaturated fatty acid, yet few studies have examined its effects on animal growth performance, with inconsistent results. Xia Zhongsheng et al. [9] reported that adding oils with different fatty acid saturation levels and double bond positions to laying hen diets had no significant effects on feed intake, laying rate, egg weight, or body weight. Friedman et al. [10] demonstrated that PUFA had no significant effect on broiler growth performance. Fébel et al. [11] found that dietary supplementation with safflower oil, soybean oil, linseed oil, or lard did not affect broiler growth performance. Wang Shuang et al. [12] reported that dietary linoleic acid levels of 0.55%, 0.75%, 0.95%, 1.15%, 1.35%, and 1.55% had no significant effect on laying performance of ducks at the onset of lay, but a linoleic acid level of 0.95% yielded the highest laying rate, maximum egg weight and daily egg mass, and lowest feed-to-egg ratio. Zhang Zhe et al. [13] showed that adding different PUFA levels (0, 150, 250, 350 mg/kg) to diets improved broiler feed conversion ratio and reduced feed-to-gain ratio. The present study indicates that dietary linoleic acid levels of 0.92%–1.12% during weeks 5–16 significantly or extremely significantly increased body weight and ADG while significantly reducing F/G in Wulong geese. These results suggest that linoleic acid promotes growth not by increasing feed intake but by improving feed utilization. The mechanisms and effects of linoleic acid on growth performance across animal species require further investigation.

3.2 Effects of Dietary Linoleic Acid Level on Slaughter Performance of Geese

Dressing percentage is a meat production index that effectively measures meat performance. Jia Rumin et al. [14] considered a dressing percentage above 80% to indicate good meat performance. Since Wulong geese achieved dressing percentages above 80%, their meat performance is considered good. Breast muscle percentage and leg muscle percentage characterize poultry meat performance, which is affected by breed, diet, and dietary balance. Pinchasov et al. [15] reported no significant difference between n-6 and n-3 PUFA effects on abdominal fat deposition in broilers. Numerous studies have shown that broilers fed diets containing unsaturated fatty acids exhibit improved growth performance and reduced fat deposition compared to those fed saturated fatty acids. Broiler fat deposition is susceptible to dietary fat type; feeding diets high in PUFA reduces abdominal fat deposition, and as abdominal fat decreases, fat deposition in other locations also decreases [16–17]. Cortinas et al. [18] found that increasing dietary PUFA content reduced subcutaneous fat content in broilers. Wang Yuanxiao et al. [19] studied the effects of mixed fats (lard and soybean oil) on yellow-feathered broilers and found no significant differences in carcass, semi-eviscerated, or eviscerated percentages among groups with lard proportions of 0%, 25%, 50%, 75%, and 100%; however, the 50% lard group had 15.1% higher breast muscle percentage and 42.4% lower abdominal fat percentage than the 100% lard group. The present study demonstrates that linoleic acid supplementation at 1.09%–1.12% significantly increased dressing percentage and breast muscle percentage while reducing abdominal fat percentage in geese. Although no significant effects were observed on semi-eviscerated percentage, eviscerated percentage, or leg muscle percentage across supplementation groups, all showed increasing trends compared to the control group. Numerous studies have confirmed that PUFA significantly reduces abdominal fat deposition [20–22], consistent with our findings. However, no specific studies on linoleic acid effects on Wulong goose slaughter performance have been reported, and the underlying mechanisms require further investigation.

3.3 Effects of Dietary Linoleic Acid Level on Meat Quality of Geese

Meat color is a comprehensive indicator reflecting muscle physiological, biochemical, and microbiological changes. In broilers, L* values >53 indicate excessive lightness, 48<L<*53 indicate normal color, and L*<46 indicate dark meat [19]. Meat color results from myoglobin and residual hemoglobin, and is also affected by myoglobin content, oxidation status, and surface light reflectance [23]. This study shows that L* values were within the normal range at dietary linoleic acid levels of 0.72%-1.12%, while a* values peaked at levels exceeding 1.12%, indicating that linoleic acid can effectively improve meat color to approach consumer preferences.

Shear force is a primary objective indicator for evaluating meat tenderness and an important measure of consumer satisfaction with meat texture; lower shear force values indicate more tender meat, while higher values indicate tougher meat [24]. Tenderness primarily depends on muscle myofibrils and connective tissue, with intramuscular fat improving tenderness by affecting their status and quantity. Fat content positively correlates with tenderness, though excessive unsaturated fatty acids can reduce tenderness. Our results show that shear force was minimized at a dietary linoleic acid level of 1.12%, but increased at higher levels. Therefore, excessive linoleic acid supplementation is not recommended for optimal tenderness.

Water loss rate is an important indicator of water-holding capacity, which is a crucial meat quality parameter affecting color, flavor, nutritional content, juiciness, tenderness, and economic value [25-26]. pH is not only a direct indicator of muscle acidity but also directly affects heat tolerance, cooking loss, and processing performance, making it one of the most important meat quality indicators [27]. Living muscle pH is slightly alkaline at approximately 7.2, but decreases post-slaughter due to lactic acid formation [28]. In this study, water loss rate was significantly reduced at a dietary linoleic acid level of 1.12%, while pH ranged from 6.19-6.22 at levels exceeding 1.12%, indicating good water-holding capacity in goose muscle.

3.4 Effects of Dietary Linoleic Acid Level on Nutrient and Energy Utilization of Geese

Oils are characterized by high energy content, easy absorption, and ready utilization. Dietary oil supplementation slows chyme passage, increases digestion time, and thereby improves carbohydrate and protein digestion and absorption in the duodenum [29]. Fatty acid digestion and absorption rates are highly correlated with unsaturation degree. Freeman et al. [30] demonstrated that unsaturated fatty acids are more easily digested and absorbed than saturated fatty acids. Gera et al. [31] showed that corn oil rich in linoleic acid was more digestible for piglets than lard or tallow, with average post-weaning digestibility rates of 84.2%, 77.0%, and 75.4%, respectively. Ketels et al. [32] found that increasing saturated fatty acid levels from animal fats reduced digestibility, while higher unsaturation increased metabolizable energy values. When unsaturated fatty acids predominate, synergistic effects between added unsaturated fatty acids and basal dietary saturated fatty acids influence fat utilization. Vegetable oils rich in unsaturated fatty acids have lower energy loss and higher metabolizable energy than animal oils rich in saturated fatty acids. Alao et al. [33] confirmed that vegetable oils with more unsaturated fatty acids had lower fecal energy loss and higher metabolizable energy than animal oils with more saturated fatty acids. Studies have confirmed that interactions between PUFA and long-chain saturated fatty acids affect energy values, producing additional metabolizable energy through synergistic effects [34] that influence fat utilization. Calcium absorption depends on its form in food and dietary factors that inhibit or promote absorption; long-chain saturated fatty acids in diets can limit calcium absorption [35]. Research indicates that arachidonic, oleic, and linoleic acids can stimulate calcium release from sarcoplasmic reticulum, but adding fatty acids before calcium ion (Ca^{2+}) enrichment inhibits calcium absorption [36]. Saturated fatty acids can form insoluble calcium soaps that affect calcium absorption. This study demonstrates that linoleic acid levels of 0.92%-1.12% significantly improved CP, EE, calcium, and phosphorus utilization, reduced fecal nitrogen, and increased deposited nitrogen and nitrogen utilization, consistent with previous research. These results indicate that linoleic acid, as an essential fatty acid, promotes nutrient absorption, accelerates animal growth, and improves nutrient utilization.

In conclusion, appropriate dietary linoleic acid levels can significantly increase body weight, ADG, dressing percentage, and breast muscle percentage while reducing F/G and abdominal fat percentage in geese. Appropriate linoleic acid levels can significantly increase muscle L* and a* values while decreasing shear force and water loss rate. Appropriate linoleic acid levels can significantly improve CP, EE, calcium, and phosphorus utilization, increase deposited nitrogen and nitrogen utilization, and reduce fecal nitrogen excretion. The recommended dietary linoleic acid level for 5-16 week-old meat geese is 0.92%-1.12%.

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