Effects of Different Dietary Crude Fiber Levels on Growth Performance, Slaughter Performance, Meat Quality, and Gastrointestinal Tract and Immune Organ Development in Growing Meat Rabbits (Postprint)

Authors: Zhang Nanbin, Sun Yingchao, Zhao Xiaoyu, Liu Gongyan, Li Fuchang, Zhu Yanli

Date: 2018-12-24T00:00:00+00:00

Abstract

This experiment aimed to investigate the effects of different dietary crude fiber levels on growth performance, slaughter performance, meat quality, and gastrointestinal tract and immune organ development in growing meat rabbits. One hundred fifty 35-day-old weaned meat rabbits with similar body weight and good health status were randomly divided into 3 groups, with 50 replicates per group and 1 rabbit per replicate. The three groups were fed experimental diets with low (crude fiber level 14.32%, LF group), medium (crude fiber level 18.46%, MF group), and high (crude fiber level 22.37%, HF group) crude fiber levels, respectively. The pre-trial period lasted 7 days, and the formal trial period lasted 23 days. The results showed that: 1) Different dietary crude fiber levels had significant or extremely significant effects on average daily gain (P=0.001 2), average daily feed intake (P=0.021 9), and feed conversion ratio (P=0.000 1) of growing meat rabbits. The average daily gain of rabbits in the HF group was extremely significantly lower than that in the LF and MF groups (P<0.01), and the feed conversion ratio of rabbits in the LF group was extremely significantly lower than that in the MF and HF groups (P<0.01). 2) Different dietary crude fiber levels had significant effects on pre-slaughter live weight (P=0.018 0), semi-eviscerated weight (P=0.036 6), and eviscerated weight (P=0.034 1) of growing meat rabbits, but had no significant effects on semi-eviscerated dressing percentage and eviscerated dressing percentage (P>0.05). 3) Different dietary crude fiber levels had no significant effects on muscle pH and lightness (L*), redness (a*), and yellowness (b*) values of growing meat rabbits (P>0.05). 4) Different dietary crude fiber levels had significant effects on relative stomach

weight (P=0.011 5), relative cecum weight (P=0.022 0), relative stomach content weight (P=0.031 1), and relative cecum content weight (P=0.031 1) of growing meat rabbits, and all were significantly higher in the HF group than in the LF group (P<0.05). 5) Different dietary crude fiber levels had significant or extremely significant effects on thymus weight (P=0.005 2), spleen weight (P=0.006 8), and liver weight (P=0.033 8) of growing meat rabbits, and all were significantly or extremely significantly lower in the HF group than in the LF group (P<0.05 or P<0.01). The spleen index of rabbits in the LF and MF groups was significantly higher than that in the HF group (P<0.05). Based on the measured indices in this experiment, the appropriate dietary fiber level for growing meat rabbits from weaning (35 days of age) to 65 days of age is 14.32%-18.46%.

Full Text

Effects of Dietary Different Crude Fiber Level on Growth Performance, Slaughter Performance, Meat Quality and Gastrointestinal and Immune Organs Development of Growing Meat Rabbits

ZHANG Nanbin, SUN Yingchao, ZHAO Xiaoyu, LIU Gongyan, LI Fuchang, ZHU Yanli*

College of Animal Science and Technology, Shandong Agricultural University, Tai' an 271018, China

Abstract

This experiment was conducted to investigate the effects of dietary crude fiber level on growth performance, slaughter performance, meat quality, and gastrointestinal and immune organ development in growing meat rabbits. One hundred fifty healthy 35-day-old weaned meat rabbits with similar body weight were randomly divided into 3 groups, each consisting of 50 replicates with 1 rabbit per replicate. The three groups were fed experimental diets with low (crude fiber level 14.32%, LF group), medium (crude fiber level 18.46%, MF group), and high (crude fiber level 22.37%, HF group) crude fiber levels. The adaptation period lasted 7 days, followed by a 23-day formal experimental period. The results showed: (1) Dietary crude fiber level had significant or highly significant effects on average daily gain (P=0.0012), average daily feed intake (P=0.0219), and feed-to-gain ratio (P=0.0001) of growing meat rabbits. The average daily gain of rabbits in the HF group was significantly lower than that in the LF and MF groups (P<0.01), while the feed-to-gain ratio in the LF group was significantly lower than that in the MF and HF groups (P<0.01). (2) Dietary crude fiber level significantly affected live body weight (P=0.0180), half-eviscerated weight (P=0.0366), and fully eviscerated weight (P=0.0341), but had no significant effect on half-eviscerated dressing percentage or fully eviscerated dressing percent-

age (P>0.05). (3) Dietary crude fiber level had no significant effects on muscle pH or lightness (L*), redness (a*), and yellowness (b*) values (P>0.05). (4) Dietary crude fiber level significantly affected stomach relative weight (P=0.0115), cecum relative weight (P=0.0220), stomach content relative weight (P=0.0311), and cecum content relative weight (P=0.0311), with the HF group being significantly higher than the LF group (P<0.05). (5) Dietary crude fiber level had significant or highly significant effects on thymus weight (P=0.0052), spleen weight (P=0.0068), and liver weight (P=0.0338), with the HF group being significantly or highly significantly lower than the LF group (P<0.05 or P<0.01). The spleen index of rabbits in the LF and MF groups was significantly higher than that in the HF group (P<0.05). Based on comprehensive evaluation of all measured indicators, the appropriate dietary crude fiber level for growing meat rabbits from weaning (35 days) to 65 days of age is 14.32%-18.46%.

Keywords: crude fiber; meat rabbit; growth performance; gastrointestinal tract; immune organs

Corresponding author, lecturer, E-mail: ylz@sdau.edu.cn

Rabbits are monogastric herbivores whose nutritional physiology characteristics determine their gastrointestinal tract' s dependence on fiber. Crude fiber (CF) is of great significance to rabbits, as dietary CF level not only determines feed consumption and nutrient supply but also affects rabbit growth, production performance, nutrient absorption and utilization, and health status. Therefore, research on rabbit utilization of fiber feed resources has received widespread attention. NRC (1977) [1] recommended that the appropriate dietary CF level for growing meat rabbits is 10%-20%. De Blas et al. [2] stipulated in their rabbit feeding standards that the CF requirement for pre-weaning rabbits is 12% and 13% post-weaning. Practice has proven that the proportion of roughage in rabbit diets is generally 30%-50%, with CF levels in complete compound feeds for growing rabbits typically being 140-180 g/kg dry matter [3]. Appropriate dietary CF levels in rabbit diets are necessary to ensure reasonable dietary structure and maintain normal digestive physiology, as they can reduce morbidity and mortality [4-5] and maintain high chyme flow rate in the intestine to avoid reduced feed intake due to accumulation of digesta in the cecum [6-7]. Both excessive and insufficient dietary CF have adverse effects on rabbit growth performance. Bennegadi et al. [4] found that when rabbits were fed low-CF diets relative to standard diets, average daily gain (ADG) decreased by 12% during 28-42 days of age and 25% during 43-56 days of age; average daily feed intake (ADFI) decreased by 32% and ADG decreased by 10% throughout the entire 28-70 day experimental period. Aboul-Ela et al. [8] reported that 4-6 week-old rabbits fed high-CF diets achieved better weight gain and lower mortality during 7-12 weeks of age; however, when fed low-CF diets, digestibility and nutritional value improved and growth performance during the fattening period was enhanced, but weight gain was poor and mortality was high during early weaning. Additionally, dietary CF level greatly affects rabbit reproductive per-

formance. Dou Ruhai et al. [9] and Tian Jinji [10] both concluded that higher dietary CF levels are beneficial for increasing litter size in does.

The first month post-weaning is a critical period for gastrointestinal development in rabbits, and fiber plays an important regulatory role in the gastrointestinal tract. This study investigated the effects of low, medium, and high CF level diets on growth performance, slaughter performance, meat quality, and gastrointestinal and immune organ development in meat rabbits from weaning (35 days) to 65 days of age, aiming to determine the appropriate dietary CF level for 35–65 day-old growing meat rabbits and provide a reasonable basis for formulating rabbit feeding standards in China.

1. Materials and Methods

1.1 Experimental Animals and Diets

One hundred fifty healthy 35-day-old weaned New Zealand meat rabbits with an average body weight of (1343±40) g, half male and half female, were randomly divided into 3 groups according to sex and body weight, with 50 replicates per group and 1 rabbit per replicate. The three groups were fed experimental diets with low (CF level 14.32%, LF group), medium (CF level 18.46%, MF group), and high (CF level 22.37%, HF group) crude fiber levels. The adaptation period lasted 7 days, followed by a 23-day formal experimental period. The experimental diets were formulated according to NRC (1977) [1] and De Blas et al. [2] feeding standards for growing rabbits, with composition and nutrient levels shown in Table 1 . All feed ingredients for each group were ground through a 1.5 mm sieve, pelleted using a cold-pelleting process into 4–6 mm diameter pellets, dried at 65°C, sealed in plastic bags, and stored in a ventilated, dry, dark place.

1.2 Feeding Management

Before the experiment, the rabbit house was thoroughly cleaned, washed, and disinfected. Rabbits were housed individually in cages. After a 7-day adaptation period, the 23-day formal experimental period began. During the experiment, rabbits were fed twice daily at 06:00 and 18:00, with free access to feed and water. Routine immunization procedures were followed, with natural lighting and ventilation, and the house temperature was maintained at 15–25°C.

1.3 Measurement Indicators

1.3.1 Growth Performance Body weight was measured and recorded at the beginning and end of the experiment, and feed consumption during the experimental period was recorded to calculate average daily feed intake (ADFI), average daily gain (ADG), and feed-to-gain ratio (F/G).

1.3.2 Slaughter Performance On the final day of the experiment, 8 rabbits from each group with body weight close to the group average were selected, weighed to record live body weight, and body length was measured as the length from neck to tail root using a soft ruler. After exsanguination via jugular vein, rabbits were immediately skinned. Forelimbs were removed at the carpal joints and hindlimbs at the hock joints, and the intestines and contents were removed (while retaining the head, thoracic organs, liver, kidneys, and perirenal fat) and weighed to obtain half-eviscerated weight. The half-eviscerated weight minus the head and all internal organs (retaining only kidneys and perirenal fat) was recorded as fully eviscerated weight, and half-eviscerated dressing percentage and fully eviscerated dressing percentage were calculated.

1.3.3 Meat Quality After slaughter, 3 cm × 4 cm samples of the left longissimus dorsi and biceps femoris muscles were removed using a scalpel for determination of muscle pH at 45 min and meat color. Muscle pH was measured by inserting the probe of a Mettler MP120 pH meter 3 mm into the muscle at the fifth rib of the longissimus dorsi. Meat color was measured using a Japanese CR-10 colorimeter in CIE-Lab mode, with three cuts made on the longissimus dorsi to record lightness (L*), redness (a*)*, and yellowness (b*) values.

1.3.4 Gastrointestinal Development After exsanguination via jugular vein, the abdominal cavity was immediately opened, and after ligation of relevant parts, the digestive tract was removed. Small intestinal loops were carefully separated from the mesentery, and natural length was measured using a soft ruler as small intestine length. The ratio of small intestine length to body length was calculated as relative small intestine length. The stomach, small intestine, and cecum were washed free of contents, excess moisture was removed on filter paper, and weights were recorded as digestive tract weights. The proportion of each digestive tract weight to live body weight was calculated as relative weight. The weight of ligated stomach and cecum minus their respective net weights was recorded as content weight, and relative content weight was calculated.

1.3.5 Immune Organ Development After slaughter, the thymus, spleen, and liver were carefully dissected and weighed individually. Their ratios to live body weight were calculated as respective immune organ indices.

1.4 Data Processing

Data were analyzed using the GLM procedure of SAS 9.1.3 statistical software, with Duncan' s multiple range test used for multiple comparisons. Results are expressed as mean ± standard error, with $P<0.05$ indicating significant difference and $P<0.01$ indicating highly significant difference.

2. Results

2.1 Effects of Dietary Crude Fiber Level on Growth Performance

As shown in Table 2 , with no significant difference in initial body weight (P=0.8870), dietary crude fiber level had a highly significant effect on ADG of growing meat rabbits (P=0.0012). ADG gradually decreased with increasing dietary CF level, with the HF group being significantly lower than the LF and MF groups (P<0.01). Dietary crude fiber level significantly affected ADFI (P=0.0219), with ADFI in the HF and MF groups being significantly higher than in the LF group (P<0.05), but no significant difference between HF and MF groups (P>0.05). Dietary crude fiber level had a highly significant effect on F/G (P=0.0001), with the LF group being significantly lower than the MF and HF groups (P<0.01), and the MF group being significantly lower than the HF group (P<0.01).

2.2 Effects of Dietary Crude Fiber Level on Slaughter Performance

As shown in Table 3 , dietary crude fiber level significantly affected live body weight (P=0.0180), half-eviscerated weight (P=0.0366), and fully eviscerated weight (P=0.0341), all of which decreased with increasing dietary CF level, with the HF group being significantly lower than the LF group (P<0.05). Dietary crude fiber level had no significant effect on half-eviscerated dressing percentage or fully eviscerated dressing percentage (P>0.05).

2.3 Effects of Dietary Crude Fiber Level on Meat Quality

As shown in Table 4 , dietary crude fiber level had no significant effects on muscle pH or L*, a*, and b* values of growing meat rabbits (P>0.05).

2.4 Effects of Dietary Crude Fiber Level on Gastrointestinal Development

As shown in Table 5 , dietary crude fiber level significantly affected stomach relative weight (P=0.0115), cecum relative weight (P=0.0220), stomach content relative weight (P=0.0311), and cecum content relative weight (P=0.0311), all of which increased with increasing dietary CF level, with the HF group being significantly higher than the LF group (P<0.05). Dietary crude fiber level had no significant effect on small intestine relative length or small intestine relative weight (P>0.05).

2.5 Effects of Dietary Crude Fiber Level on Immune Organ Development

As shown in Table 6 , dietary crude fiber level had significant or highly significant effects on thymus weight (P=0.0052), spleen weight (P=0.0068), and liver weight (P=0.0338), with the HF group being significantly or highly significantly lower than the LF group (P<0.05 or P<0.01). Dietary crude fiber level significantly

affected spleen index (P=0.0128) but had no significant effect on thymus index or liver index (P>0.05). The spleen index of rabbits in the LF and MF groups was significantly higher than that in the HF group (P<0.05), with no significant difference between the LF and MF groups (P>0.05).

3. Discussion

3.1 Effects of Dietary Crude Fiber Level on Growth Performance

Rabbits are small monogastric herbivores, and De Blas et al. [11] demonstrated that fiber is one of the main components of rabbit diets. Depending on the analytical method, dietary CF levels in complete compound feeds for growing rabbits range from 14% to 18%, and either excessive or insufficient dietary fiber proportions adversely affect rabbit growth [12]. The present study showed that feeding high-CF diets to growing meat rabbits did not result in high growth performance. When dietary acid detergent fiber (ADF) levels ranged from 20.7% to 25.39% and neutral detergent fiber (NDF) levels ranged from 31.72% to 37.76%, ADG of growing meat rabbits peaked in the LF group and decreased with declining ADF and NDF levels. When ADF level was 20.70% and NDF level was 31.72%, the F/G of growing meat rabbits was lowest. ADFI of growing meat rabbits increased with increasing ADF and NDF levels, consistent with the report by Chiou et al. [13]. Chao Hongyu et al. [14] reported that adding 19% ADF to diets resulted in highest ADG, lowest F/G, and optimal growth performance in rabbits. Yang Sha [15] concluded that a dietary CF level of 13% resulted in higher ADG and feed conversion in growing meat rabbits. These reports are generally consistent with the present study results but differ from Gidenne et al. [5], who reported that ADFI decreased with decreasing dietary ADF levels and did not affect ADG throughout the entire fattening period (28–77 days of age).

3.2 Effects of Dietary Crude Fiber Level on Slaughter Performance and Meat Quality

Rabbit meat has the advantages of high protein, high lysine, high niacin, high digestibility, low fat, low cholesterol, and low energy density, and is favored by consumers as “beauty meat”and “intelligence meat”by experts [16]. Rabbit meat quality largely depends on rabbit nutrition, though different nutritional levels affect different meat quality indicators differently. Parigr et al. [17] designed experimental diets with three different CF levels of 13.8%, 16.3%, and 19.8%, and found that CF level had no significant effect on rabbit dressing percentage or carcass fat content. Carrilho et al. [18] showed that feeding 5–8 week-old rabbits diets with CF levels of 14.3%, 18.0%, and 20.5% (air-dry basis) followed by fattening diets until slaughter resulted in no significant differences in physical and sensory characteristics of rabbit meat such as pH, color, water-holding capacity, and toughness among different diets. The present study showed that dietary CF level had no significant effect on meat quality, consistent with the above studies. Dietary CF level and the ratio of digestible fiber to ADF had no

significant effect on rabbit carcass and meat quality, and even increasing dietary CF level during the final week of fattening did not significantly adversely affect rabbit slaughter performance or muscle pH [19].

3.3 Effects of Dietary Crude Fiber Level on Gastrointestinal Development

From weaning to 2 months of age, high-CF diets are beneficial for digestive tract development due to the strong stimulating effect of plant-based feed on the digestive tract. Margüenda et al. [19] found that fiber plays an important role in controlling gastrointestinal development. Tao et al. [20] showed that increasing dietary NDF levels in 2–3 month-old rabbits increased net weights of the stomach, cecum, and colon as well as colon length. Chao et al. [21] confirmed that stomach relative weight, small intestine relative weight, cecum weight, cecum content weight, and cecum relative weight all increased with increasing dietary ADF level. The present study showed that stomach relative weight and cecum relative weight of growing meat rabbits gradually increased with increasing dietary CF level, with the HF group being significantly higher than the LF group, consistent with the above studies. The rabbit stomach plays an important role in nutrient digestion, and the cecum is extremely well-developed (accounting for 49% of total digestive tract capacity) and plays an important role in CF digestion. De Blas et al. [22] and García et al. [23] found that fiber can affect feed intake and chyme retention time in the cecum, with stomach content quantity increasing as fiber level increased. Jehl et al. [24] noted that cecum volume expansion is closely related to ADF intake. García et al. [7] observed that the ratio of cecum content to body weight increased with increasing dietary NDF level. The present study found that both stomach relative weight and cecum relative weight increased with increasing dietary CF level, which may be largely related to increased ADFI.

3.4 Effects of Dietary Crude Fiber Level on Immune Organ Development

Immune organs are the important material basis for immune function in animals and constitute the tissue structure for executing immune functions, playing crucial roles in the immune process. The thymus is the central immune organ where T lymphocytes develop and proliferate, playing an important role in lymphocyte formation and differentiation. The spleen is a peripheral immune organ where T and B lymphocytes reside and where immune responses to antigen stimulation occur. The liver contains highly phagocytic Kupffer cells that can recognize surface receptors of immunoglobulins and complement and can phagocytose or pinocytose bacteria, viruses, and senescent cells from the blood, making it an important immune organ for purifying body fluids [25]. Immune indices can reflect animal immune function to a certain extent; it is generally believed that larger immune indices indicate stronger immunity in healthy animals, decreased immune organ weight indicates immunosuppression, while increased immune or-

gan weight indicates immune enhancement [26]. Dietary CF supplementation can promote lymphoid follicle growth in lymphoid tissues [27], and studies have shown that appropriate dietary CF levels can increase secretory immunoglobulin A (sIgA) antibody content in the intestine [28]. These reports demonstrate that dietary CF can improve rabbit immune status, including increasing thymus and spleen indices [29]. However, the present study showed that immune organ weights (thymus, spleen, and liver) were significantly affected by dietary CF level, with the highest thymus and liver indices observed at 14.32% CF level. This may be because optimal growth and development at this dietary CF level resulted in the best immune status.

4. Conclusion

Based on comprehensive evaluation of growth performance, slaughter performance, meat quality, and gastrointestinal and immune organ development indicators, the appropriate dietary crude fiber level for growing meat rabbits from weaning (35 days) to 65 days of age is 14.32%–18.46%.

References

[1] NRC. Nutrient Requirements of rabbits[S]. 2nd ed. Washington, D.C.: National Academy Press, 1977.

[2] DE BLAS C, WISEMAN J. The nutrition rabbit[M]. New York: CABI Publishing, 1998: 297–308.

[3] LI Fuchang. Rabbit Nutrition[M]. Beijing: China Agriculture Press, 2009: 37–38.

[4] BENNEGADI N, GIDENNE T, LICOIS L. Impact of fiber deficiency and sanitary status on non-specific enterropathy of the growing rabbit[J]. Animal Research, 2001, 50(5): 401–413.

[5] GIDENNE T, ARVEUX P, MSDEC O. The effect of the quality of dietary lignocellulose on digestion, zootechnical performance and health of growing rabbits[J]. Animal Science, 2001, 73(1): 97–104.

[6] BELLIER R, GIDENNE T. Consequence of reduced fiber intake on digestion, rate of passage and caecal microbial activity in young rabbits[J]. British Journal of Nutrition, 1996, 75(3): 353–363.

[7] GARCÍA J, CARABAÑO R, DE BLAS J C. Effect of fiber source on cell wall digestibility and rate of passage in rabbits[J]. Journal of Animal Science, 1999, 77(4): 898–905.

[8] ABOUL-ELA S, ABD EL-GALIL K, ALI F A. Effect of dietary fiber and energy levels on performance of post-weaning rabbits[J]. World Rabbit Science, 2000, 8(S1): 61–75.

[9] DOU Ruhai, GE Dawei, YANG Peilin, et al. Study on appropriate nutritional levels for breeding does[J]. Shanghai Laboratory Animal Science, 1995, 15(2): 91-93.

[10] TIAN Jinji. Effect of different nutritional level diets on reproductive performance of does[J]. Heilongjiang Animal Science and Veterinary Medicine, 2000(8): 26.

[11] DE BLAS C, GARCÍA J, CARABAÑO R. Role of fibre in rabbit diets. A review[J]. Annales de Zootechnie, 1999, 48(1): 3-13.

[12] YANG Guiqin, SUN Jiayi, GUO Dongxin, et al. Effects of dietary fiber source and crude fiber level on nutrient digestibility, intestinal digestive enzyme activity, and cecal microflora diversity in meat rabbits[J]. Chinese Journal of Animal Nutrition, 2016, 28(9): 2861-2871.

[13] CHIOU P W S, YU B, LIN C. Effect of different components of dietary fiber on the intestinal morphology of domestic rabbits[J]. Comparative Biochemistry and Physiology Part A: Physiology, 1994, 108(4): 629-638.

[14] CHAO Hongyu, LI Fuchang. Effects of dietary ADF level on intestinal health, nutrient digestion, and production performance of weaned meat rabbits[J]. China Feed, 2012(5): 11-13, 16.

[15] YANG Sha. Effects of dietary crude fiber level on intestinal structure and weight gain in rabbits[D]. Master' s Thesis. Ya' an: Sichuan Agricultural University, 2013.

[16] WANG Jianqiao, FAN Yifei. Investigation on current status and development strategies of rex rabbit production in Cixi City[J]. Zhejiang Animal Husbandry and Veterinary Medicine, 2003(4): 15-16.

[17] PARIGR B R, XICCATO G, ZOTTE A D, et al. Effects de differents niveaux de fibre alimentaire sur l' utilisation digestive et la qualité bouchère chez le lapin[C]//Proceedings of 6èmes Journées de la Recherche Cunicole. Larochelle: INRA-ITAVI, 1994: 347-354.

[18] CARRILHO M C, CAMPO M M, OLLETA J L, et al. Effect of diet, slaughter weight and sex on instrumental and sensory meat characteristics in rabbits[J]. Meat Science, 2009, 82(1): 37-43.

[19] MARGÜENDA I, NICODEMUS N, VADILLO S, et al. Effect of dietary type and level of fibre on rabbit carcass yield and its microbiological characteristics[J]. Livestock Science, 2012, 145(1/2/3): 7-12.

[20] TAO Zhenyu, LI Fuchang. Effects of dietary neutral detergent fibre on production performance, nutrient utilization, caecum fermentation and fibrolytic activity in 2-3-month-old New Zealand rabbits[J]. Journal of Animal Physiology and Animal Nutrition, 2006, 90(11/12): 467-473.

[21] CHAO Hongyu, LI Fuchang. Effect of level of fiber on performance and digestion traits in growing rabbits[J]. Animal Feed Science and Technology, 2008,

144(3/4): 279-291.

[22] DE BLAS J C, WISEMAN J, FRAGA M J, et al. Prediction of digestible energy and digestibility of gross energy of feeds for rabbits. 2. Mixed diets[J]. Animal Feed Science and Technology, 1992, 39(1/2): 39-59.

[23] GARCÍA J, NICODEMUS N, CARABAÑO R, et al. Effect of inclusion of defatted grape seed meal in the diet on digestion and performance of growing rabbits[J]. Journal of Animal Science, 2002, 80(1): 162-170.

[24] JEHL N, GIDENNE T. Replacement of starch by digestible fiber in feed for the growing rabbit. 2. Consequences for microbial activity in the caecum and on incidence of digestive disorders[J]. Animal Feed Science and Technology, 1996, 61(1/2/3/4): 193-204.

[25] WANG Fen, ZUO Mingxue. Human and Animal Physiology[M]. 2nd ed. Beijing: Higher Education Press, 2001.

[26] LI Sufen, FENG Minshan, YAN Guohong. Effects of biochemical fulvic acid on production performance and immune organs of broiler chickens[J]. China Feed, 2000(14): 14-15.

[27] CARABAÑO R, BADIOLA I, CHAMORRO S, et al. New trends in rabbit feeding: influence of nutrition on intestinal health[J]. Spanish Journal of Agricultural Research, 2008, 6(S1): 15-25.

[28] ZHU Y L, WANG Y, WANG X P, et al. Effects of dietary fiber and starch levels on the non-specific immune response of growing rabbits[J]. Livestock Science, 2013, 155(2/3): 285-293.

[29] TAO Zhenyu, LI Fuchang. Effects of dietary NDF levels on production performance, digestibility, metabolism and caecum fermentation of weaning to two-month-old meat rabbits[J]. Acta Zoonutrimenta Sinica, 2005, 17(4): 56-61.

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