核黄素的研究进展

核黄素又称维生素 B2，是水溶性维生素之一，在干热和酸性环境中很稳定，但在碱性环境中易分解。核黄素是动物体内碳水化合物、脂肪、蛋白质和核酸代谢过程中多种必需酶的组成成分。在动物体内主要以黄素腺嘌呤二核苷酸（Flavin adenine dinucleotide FAD）和黄素单核苷酸（Flavin mononudeofide FMN）参与氧化还原反应，在自然状态下几乎没有游离态的核黄素，FAD 是其在动物体内的主要存在形式。已知在动物和微生物中有 100 多种的酶与 FAD 和 FMN 结合。

核黄素对家禽的影响研究相对较多。仔鸡的生长发育很大程度上决定了鸡的生长和繁殖性能，从而决定其经济效益。研究表明，仔鸡料中添加 14.4mg/kg 的核黄素能促进胸腺和法氏囊的发育，胸腺和法氏囊是新城疫抗体产生的主要器官，因此核黄素的添加可提高新城疫抗体水平，并降低仔鸡死亡率[1]。同样有研究表明 14.4mg/kg 的核黄素的添加可促进仔鸡的生长速度[2]，并提高肉仔鸡的抗感染能力和免疫力[3]。家禽的经济效益主要由其体增重、肌肉率和料重比等决定。饲料中核黄素的添加可提高肉鸡后期体增重，并降低肌肉滴水损失[4]。北京鸭体内核黄素缺乏时，可引起血浆胆固醇和甘油三酯含量升高，并升高死亡率和料重比，降低体重和肌肉率[5]。人类体内核黄素储存量低，需每日从食物中获取，适量核黄素的添加可提高蛋黄和蛋清中核黄素含量[6]，提高家禽的经济效益。

在大鼠中的研究发现，核黄素的添加可提高大鼠的免疫力和存活率[7]。核黄素缺乏引起大鼠全血谷胱甘肽还原酶活性系数升高及全血还原型谷胱甘肽含量降低，全血丙二醛浓度升高及红细胞超氧化物歧化酶活性降低，这会引起大鼠肝脏内脂质过氧化物浓度的增加，从而引起脂肪肝[8,9]。另有研究表明，缺乏核黄素的大鼠中分离出的红细胞膜的流动性显著降低。流动性的降低伴随着膜结合酶乙酰胆碱酯酶活性的增加，从而引起细胞应对过氧化损伤的能力下降，这可能会导致膜的流动性和功能发生变化[10,11]。另外，核黄素的缺乏也会引起大鼠体内山梨糖醇途径增强，而过量的山梨糖醇会引起消化紊乱[12]。因此，动物对核黄素的足量摄取尤为重要。

有文献表明对奶牛进行十二指肠灌注 0.3g/d 的核黄素可提高奶牛的抗氧化能力，降低脂质过氧化物堆积[13]。核黄素的添加也可提高奶牛的免疫应答，降低牛奶中体细胞数量[14]（如表 1）。奶牛摄入核黄素不足，会造成奶牛 $HepG_2$ 细胞中蛋白质和 DNA 损伤[15]。核黄素对反刍动物影响的研究较少，核黄素对反刍动物的影响机理仍有待进一步研究。

Research progress of riboflavin

Riboflavin is one of water-soluble vitamins, also known as vitamin B2. Which is stable in dry heat and acidic environments, but decomposes easily in alkaline environments. Riboflavin is a component of many essential enzymes for the metabolism of carbohydrates, fats, proteins and nucleic acids in animals. Flavin adenine dinucleotide (FAD) and Flavin mononudeofide (FMN) play a role in the redox reaction. In nature, there is almost no free riboflavin. The main form of existence in animals is FAD. It is known that more than 100 enzymes in animals and microorganisms bind to FAD and FMN.

There are many studies on the effects of riboflavin on poultry. The growth performance of chicks largely determines the growth and reproductive performance of chickens, and their economic benefits. Studies have shown that, the addition of 14.4mg / kg of riboflavin to the chick diets promoted the thymus and bursa of the thymus. The thymus and the bursa of the bursa are

the main organs for the production of Newcastle disease antibodies, moreover, riboflavin reduced the mortality of chicks[1]. Some studies indicated that the addition of 14.4mg/kg of riboflavin promoted the growth rate of chicks[2], and improved the anti-infection ability and immunity of broilers[3]. The economic benefit of poultry is mainly determined by its body weight gain, muscle rate and feed-to-weight ratio. The addition of riboflavin in the diets increased the body weight gain of broilers at a later stage and reduced the loss of muscle drip[4]. The lack of riboflavin in Beijing ducks can cause an increase in plasma cholesterol and triglyceride levels, increased mortality and feed-to-weight ratio, and reduced body weight and muscle rate[5]. The human body has low level of riboflavin and needs to be obtained from food every day. The addition of an appropriate amount of riboflavin can increase the riboflavin content in egg yolk and egg white[6], which increase the economic efficiency of poultry.

Studies in rats have found that the addition of riboflavin can improve the immunity and survival rate of rats[7]. Riboflavin deficiency caused an increase in the activity coefficient of glutathione reductase in blood and a decrease of glutathione in blood, an increase in the concentration of malondialdehyde in blood and a decrease in the activity of red blood cell superoxide dismutase, which can cause an increase in the concentration of lipid peroxides in the rat liver, thus can cause fatty liver[8,9]. Another study showed that the fluidity of erythrocyte membranes isolated in rats lacking riboflavin was significantly reduced. The decrease in fluidity is accompanied by an increase in the activity of the membrane-bound enzyme acetylcholinesterase, resulting in a decrease in the cell's ability to cope with peroxidative damage, which may result in changes in membrane fluidity and function[10,11]. In addition, the lack of riboflavin can also increase the sorbitol pathway in rats, and excessive sorbitol can cause digestive disorders[12]. Therefore, adequate intake of riboflavin by animals is particularly important.

Literature has shown that infusion of 0.3g/d riboflavin into the duodenum of dairy cows can increase the antioxidant capacity of dairy cows and reduce the accumulation of lipid peroxides [13]. The addition of riboflavin can also improve the immune response of dairy cows and reduce the number of somatic cells in milk[14] (Table 1). Insufficient intake of riboflavin from dairy cows can cause protein and DNA damage in HepG2 cells of dairy cows[15]. The influence of riboflavin on ruminants is seldom studied, and the mechanism of the influence of riboflavin on ruminants remains to be further studied.

[1] 王志跃, 汪张贵, 龚道清等. 日粮核黄素水平对新扬州仔鸡免疫器官发育及体液免疫的影响[J]. 动物营养学报. 2005, 17(03):21-24.
[2] 赵秀华. 日粮中铁和核黄素添加量对仔鸡生产性能、部分生化指标和免疫功能的影响[D]. 扬州大学.
[3] 张建海, 原广华, 庞全海等. 不同核黄素水平对肉仔鸡外周血细胞、免疫器官及生产性能的影响[J]. 河南农业科学. 2003,02:9-11.
[4] 李绍钰, 魏凤仙, 郝国庆等. 维生素 E 与核黄素对肉鸡生产性能及肉质的影响[J]. 河南农业科学. 2005,6:82-84.
[5] 唐静, 胡健, 江勇等. 核黄素缺乏对 1～28 日龄北京鸭生长性能、器官指数和血浆生化指标的影响[J]. 动物营养学报. 2017, 29(11):3899-3905.
[6] 赵睿, 张博, 夏芳等. 饲粮核黄素水平对产蛋期北京鸭产蛋性能、蛋品质、血浆生化指标

及血浆、蛋黄、蛋清中核黄素含量的影响[J]. 动物营养学报. 2020, 02:359-368.
[7] 王林静. 小白鼠孕期、哺乳期核黄素水平对仔鼠生长发育和免疫功能影响的研究[D].湖南医科大学.
[8] Misako T, Takayuki H. Effects of riboflavin and selenium deficiencies on glutathione and its relating enzyme activities with respect to lipid peroxide content of rat livers[J]. 1983, 29(3):283-292.
[9] 梁惠芳，柳启沛，徐京. 核黄素对大鼠脂质过氧化影响的研究[J]. 卫生研究，1999, 06:244-248.
[10] Galit L, Uri C, Yishai L, Shoshana M, et al. Riboflavin deficiency and function of rat erythrocyte membranes[J]. 1990, 120(8):857-861.
[11] 吴晖云，林利平，李珏声等. 核黄素缺乏大鼠红细胞膜流动性与脂质过氧化关系的研究[J]. 营养学报, 1993, 04:355-359.
[12] Vasanth P, Seetharam B, et al. Effect of riboflavin deficiency on sorbitol pathway in rat lens[J]. 1989, 9(10):1143-1149.
[13] 蒋亚军. 烟酸、核黄素对奶牛生产性能、抗氧化能力和免疫力的影响[D]. 石河子大学.
[14] Sato S, Hori H, Okada K. Effect of vitamin B_2 on somatic cell counts in milk of clinical Staphylococcus aureus mastitis.Veterinary Medical Science. 1999,(03):569-571.
[15] Manthey K C, Rodriguez M R, Hoi Jia Tse, et al. Riboflavin deficiency causes protein and DNA damage in HepG2 cells, triggering arrest in G1 phase of the cell cycle. Nutritional Biochemistry. 2006(03):250-260.

表 1 添加核黄素对奶牛免疫应答的影响

Table 1 Effect of adding riboflavin on the immune response of dairy cows

	每升牛奶中所含体细胞数			
DAYS AFTER FIRST INJECTION	0	3	7	14
Control	733	693	612	655
Riboflavin injected 1	679	451*	361**	436*

1Injection of 2.5 mg/kg B.W. (3 days)
SCC(x 10,000)
*p 0.05
**p 0.01