胆碱的研究进展

胆碱属 B 族维生素类，又称维生素 B4。但胆碱不同于其他的 B 族维生素作为辅酶发挥其生理功能，而是作为细胞结构发挥其生理作用。以往研究认为，日粮本身和奶牛自身生产的胆碱可满足机体对胆碱的需求。但随着养殖业集约化的快速发展，机体对胆碱的需要量可能无法得到满足，因此有必要向奶牛日粮中添加外源性胆碱。过去的研究明，如果将胆碱直接添加到奶牛的日粮中，胆碱易被瘤胃微生物降解，如果较高剂量的添加还会影响到奶牛的采食量，这些原因限制了胆碱在奶牛饲料中的作用[1]。为了防止胆碱在瘤胃中被降解和改善其适口性，就需要对胆碱进行处理，使其可以顺利通过瘤胃。目前，为使胆碱在动物体内得到充分利用，常使用过瘤胃保护胆碱（rumen protected choline, RPC）的方法对胆碱进行处理。

过瘤胃技术使胆碱在奶牛产后出现的能量负平衡状态、脂肪肝和酮病等疾病方面发挥作用。有研究表明，在奶牛日粮中添加 30g/d 的 PRC 可缓解围产期能量负平衡状态[2]，降低临床酮症和乳腺炎发病率[3]。RPC 提高了泌乳高峰期脂肪功能的效率，改善机体能量负平衡状态，从而提高产奶量并且胆碱提供游离甲基合成蛋氨酸，满足了泌乳的氨基酸需求，促进了乳蛋白的合成[2]，有研究表明，RPC 的添加可提高奶牛产奶量、乳蛋白和乳脂率[2-7]（如表 1）。

PRC 的添加还可改善奶牛的血液指标。15g/d RPC 的添加可降低血液中非酯化脂肪酸的浓度，缓解脂肪肝的发生，这是由于胆碱的缺乏会限制血液中甘油三酯的生成，导致非酯化脂肪酸在肝脏中积累更多，诱发脂肪肝[8]（如表 2）。并且 RPC 也可提高血糖、蛋氨酸、苏氨酸和异亮氨酸浓度，进而提高生产性能[9-10]。20g/d RPC 的添加可提高胰岛素的分泌，降低血液中胰高血糖素的浓度，这是由于 RPC 的添加提高了血糖浓度，从而促进胰岛素分泌[11]（如表 3）。另有 RPC 的添加对奶牛代谢机理方面的研究表明，RPC 可使奶牛脂肪酸摄取和细胞内转运的能力增加，胆碱增加了肝脏中牛奶脂肪酸转运蛋白 5 和肉碱转运蛋白 SLC22A5 的表达，促进了含载脂蛋白 B 的脂蛋白装配，如微粒体甘油三酸酯转移蛋白表达和载脂蛋白 B100 表达升高，改善碳水化合物的代谢。产犊后立即表现出升高的葡萄糖转运蛋白 2 mRNA 水平和丙酮酸羧化酶 mRNA 峰降低[12]。

总之，适量 PRC 的添加可提高奶牛生产性能，提高其经济效益。

Research progress of choline

Choline is a B vitam in group, also known as vitamin B4. But choline is different from other B vitamins as a coenzyme to play its physiological function, but its play physiological role as a cell structure. Previous studies have suggested that the choline produced by the diet and the cows themselves can meet the body's demand for choline. However, with the rapid development of intensification in the breeding industry, the body's demand for choline may not be met, so it is necessary to add exogenous choline to the cow's diet. Past studies have shown that choline is added directly to the cow's diet, choline is easily degraded by rumen microorganisms. If higher doses are added, it would affect the feed intake of the cows[1]. In order to prevent the degradation of choline in the rumen and improve its palatability, it is necessary to treat the choline so that it can pass through the rumen smoothly. At present, in order to make the best use of choline in animals, ruminal protected choline (RPC) method is often used to treat choline.

Rumen-passing technology allows choline to play a role in the negative energy balance, fatty liver and ketosis of dairy cows after delivery. Studies have shown that adding 30g/d of PRC to

dairy cow diets can alleviate negative perinatal energy balance[2] and reduce the incidence of clinical ketosis and mastitis[3]. RPC improves the efficiency of fat function at the peak of lactation and improves the body's negative energy balance, thereby increasing milk production and choline provides free methyl-synthetic methionine, which meets the amino acid requirements of lactation and promotes the synthesis of milk protein[2] Studies have shown that the addition of RPC can increase milk yield, milk protein and milk fat rate of dairy cows[2-7](Table 1).

The addition of PRC can also improve the blood index of dairy cows. The addition of 15g/d RPC can reduce the concentration of non-esterified fatty acids in the blood and relieve the occurrence of fatty liver. This is because the lack of choline will limit the production of triglycerides in the blood, resulting in the accumulation of non-esterified fatty acids in the liver. Many, induced fatty liver[8](Table 2). And RPC can also increase blood glucose, methionine, threonine and isoleucine concentration, thereby improving production performance[9-10]. The addition of 20g/d RPC can increase the secretion of insulin and reduce the concentration of glucagon in the blood. This is because the addition of RPC increases the blood glucose concentration, thereby promoting insulin secretion[11](Table 3). In addition, studies on the metabolism mechanism of dairy cows with the addition of RPC have shown that RPC can increase the capacity of dairy cows for fatty acid uptake and intracellular transport. Choline increases the expression of milk fatty acid transporter 5 and carnitine transporter SLC22A5 in the liver, promoting Assembly of lipoproteins containing apolipoprotein B, such as microsomal triglyceride transfer protein expression and increased expression of apolipoprotein B100, improves carbohydrate metabolism. Immediately after calving, elevated glucose transporter 2 mRNA levels and pyruvate carboxylase mRNA peaks decreased [12].

In short, the addition of appropriate amount of EPC can improve the performance of dairy cows and increase their economic efficiency.

[1] ERDMAN R A, SHSVER R D, VANDERSALL J H.Dietary choline for the lactating cow: possible effects on milk fatsynthesis[J]. Journal of Dairy Science, 1984, 67(2): 410-415.
[2] 陈志远，王剑飞，高健等. 过瘤胃胆碱对围产期奶牛生产性能及脂肪代谢的影响[J]. 中国奶牛. 2018, 04:10-13.
[3] ELEK P, NEWBOLD J R, GAAL T, et al. Effects of rumen-protected choline supplementation on milk production and choline supply of periparturient dairy cows[J] Animal, 2008, 2(11): 1595-1601.
[4] SHANNON D. Supplementation of rumen-protected forms of methionine, betaine, and choline to early lactation Holstein cows[J] Ph.D. Thesis. Raleigh:North Carolina State University, 2006.
[5] DAVIDSON S, HOPKINS B A, ODLE J, et al. Supplementing limited methionine diets with rumen-protected methionine, betaine and choline in early lactation Holstein cows[J]. Journal of Dairy Science, 2008, 91(4):1552-1559.
[6] SHARMA BK, ERDMAN RA. Effects of dietary and abomasally infused choline on milk production responses of lactating dairy cows[J]. Journal of Nutrition. 1989, 119(2):248-254.
[7] Zhou Z O, BULGARI M. VAILATI-RIBONI. Effect of rumen protected choline (Reashure) and rumen protected methionine on milk yield, and composition in lactating cows[J]. American Dairy Science Association. 2016, 99(61):8956-8969.
[8] COOKE R F, SILVA DEL RO N, CARAVIELLO DZ, et al. Supplemental choline for prevention and

alleviation of fatty liver in dairy cattle[J]. Journal of Dairy Science, 2007, 90(5):2413-2418.
[9] PINOTTI L, CAMPAGNOLI A, SANGALLI L, et al. Metabolism in periparturient dairy cows fed rum en-protected choline[J]. Animal Feed Science, 2004, 13(Suppll) : 551-554.
[10] BONOMI A QUARANTELLI A BONOMI B M et al. Inclusion of rumen-protected choline indiets for dairy cattle[J]. Nutrition Research Reviews. 1996, 25:413-434.
[11] 郑家三, 夏成, 张洪友等. 过瘤胃胆碱对围产期奶牛生产性能和能量代谢的影[J]. 中国农业大学学报, 2012, 17(3):114-120.
[12] Goselink J, van Baal H.C.A, Widjaja R A, et al. Effect of rumen-protected choline supplementation on liver and adipose gene expression during the transition period in dairy cattle[J]. 2013,96(2):1102-1106.

表 1　PRC 对围产期奶牛泌乳性能的影响

Table 1 Effects of PRC on lactation performance of periparturient dairy cows

项目 Items	组别 Groups	产后 15 天 15 days after parturition	产后 30 天 30 days after parturition	产后 45 天 45 days after parturition	产后 60 天 60 days after parturition
产奶量 Milk yield/(kg/d)	Ⅰ	30.12 ±6.31	30.70 ±7.04	31.50 ±5.81^{Aa}	32.90 ±5.44^{Aa}
	Ⅱ	31.05 ±4.51	32.80 ±5.11	37.28 ±6.37^{Bb}	38.09 ±5.19^{Bb}
	Ⅲ	31.42 ±4.18	33.37 ±5.71	39.55 ±6.39^{Bb}	40.93 ±5.41^{Bb}
乳脂率 Milk fat percentage/%	Ⅰ	4.27 ±0.02^{a}	4.22 ±0.03^{a}	4.17 ±0.04	4.11 ±0.04^{a}
	Ⅱ	4.28 ±0.01^{ab}	4.23 ±0.01^{ab}	4.16 ±0.03	4.12 ±0.01^{ab}
	Ⅲ	4.29 ±0.04^{b}	4.24 ±0.02^{b}	4.18 ±0.04	4.13 ±0.04^{b}
乳蛋白率 Milk protein percentage/%	Ⅰ	3.28 ±0.01^{a}	3.25 ±0.01^{Aa}	3.24 ±0.01^{a}	3.22 ±0.02^{a}
	Ⅱ	3.29 ±0.01^{ab}	3.27 ±0.01^{ABab}	3.25 ±0.02^{b}	3.23 ±0.01^{ab}
	Ⅲ	3.31 ±0.02^{b}	3.28 ±0.01^{Bb}	3.26 ±0.02^{b}	3.24 ±0.01^{b}
乳糖率 Lactose percentage/%	Ⅰ	4.52 ±0.18^{a}	4.41 ±0.18	4.21 ±0.11	4.10 ±0.17
	Ⅱ	4.53 ±0.10^{a}	4.39 ±0.10	4.25 ±0.09	4.20 ±0.09
	Ⅲ	4.64 ±0.14^{b}	4.46 ±0.17	4.30 ±0.17	4.21 ±0.26
乳总固形率 Milk TS percentage/%	Ⅰ	13.47 ±0.05^{a}	13.41 ±0.04^{Aa}	13.36 ±0.04	13.29 ±0.03
	Ⅱ	13.49 ±0.03^{ab}	13.43 ±0.01^{ABb}	13.36 ±0.01	13.29 ±0.06
	Ⅲ	13.50 ±0.03^{b}	13.44 ±0.03^{Bb}	13.37 ±0.05	13.30 ±0.03

表 2 RPC 对围产期奶牛血浆生化指标的影响

Table 2 Effects of PRC on plasma metabolic hormone indices of periparturient dairy cows

项目 Items	组别 Groups	产前 7 天 7 days before parturition	产犊当日 Calving day	产后 7 天 7 days after parturition	产后 14 天 14 days after parturition
葡萄糖 Glu/(mmol/L)	Ⅰ	3.49 ± 0.03^{Aa}	3.36 ± 0.06^{a}	3.12 ± 0.04^{a}	3.36 ± 0.07^{a}
	Ⅱ	3.63 ± 0.04^{Ab}	3.51 ± 0.06^{b}	3.11 ± 0.11^{a}	3.47 ± 0.08^{ab}
	Ⅲ	3.78 ± 0.07^{Bc}	3.53 ± 0.06^{b}	3.29 ± 0.08^{b}	3.62 ± 0.11^{b}
甘油三酯 TG/(mmol/L)	Ⅰ	0.42 ± 0.01^{Aa}	0.42 ± 0.01^{Aa}	0.43 ± 0.05^{a}	0.43 ± 0.02
	Ⅱ	0.43 ± 0.01^{ABab}	0.42 ± 0.03^{Aa}	0.44 ± 0.03^{b}	0.43 ± 0.01
	Ⅲ	0.44 ± 0.01^{Bb}	0.43 ± 0.01^{Bb}	0.44 ± 0.02^{b}	0.43 ± 0.02
非酯化脂肪酸 NEFA/(μmol/L)	Ⅰ	268.24 ± 6.15^{Bc}	278.35 ± 5.55^{Bc}	292.68 ± 4.49^{Bc}	264.58 ± 6.01^{Bc}
	Ⅱ	250.71 ± 6.88^{Bb}	262.67 ± 6.78^{Bb}	274.73 ± 4.34^{Bb}	253.15 ± 3.39^{Bb}
	Ⅲ	206.51 ± 4.50^{Aa}	242.81 ± 5.42^{Aa}	243.96 ± 8.72^{Aa}	235.13 ± 1.89^{Aa}
β－羟丁酸 BHBA/(μmol/mL)	Ⅰ	411.43 ± 11.77^{Aa}	488.10 ± 4.94^{Bb}	520.34 ± 7.04^{Bb}	475.50 ± 8.83^{Bc}
	Ⅱ	387.35 ± 7.41^{ABb}	453.09 ± 15.10^{Aa}	480.99 ± 6.50^{Aa}	434.36 ± 6.08^{Ab}
	Ⅲ	363.63 ± 10.37^{Bc}	435.36 ± 9.65^{Aa}	470.80 ± 13.12^{Aa}	413.60 ± 7.35^{Aa}
低密度脂蛋白 LDL/(mmol/L)	Ⅰ	2.08 ± 0.02^{Aa}	2.19 ± 0.03^{Aa}	1.96 ± 0.12^{Aa}	2.16 ± 0.07^{Aa}
	Ⅱ	2.12 ± 0.01^{ABab}	2.25 ± 0.02^{ABb}	2.15 ± 0.02^{ABb}	2.25 ± 0.04^{Ab}
	Ⅲ	2.15 ± 0.02^{Bb}	2.33 ± 0.03^{Bc}	2.24 ± 0.02^{Bc}	2.35 ± 0.01^{Bc}
总胆固醇 CHO/(mmol/L)	Ⅰ	3.79 ± 0.02^{Bc}	3.45 ± 0.06^{Bc}	3.80 ± 0.01^{Cc}	3.97 ± 0.01^{Bc}
	Ⅱ	3.61 ± 0.05^{Bb}	3.07 ± 0.17^{Ab}	3.57 ± 0.07^{Bb}	3.79 ± 0.07^{ABb}
	Ⅲ	3.30 ± 0.10^{Aa}	2.84 ± 0.08^{Aa}	3.15 ± 0.07^{Aa}	3.60 ± 0.09^{Aa}
总氨基酸 TAA/(mmol/L)	Ⅰ	$2\,794.09 \pm 30.61^{Aa}$	$2\,694.34 \pm 14.44^{a}$	$2\,706.72 \pm 9.37^{a}$	$2\,796.63 \pm 17.17$
	Ⅱ	$2\,836.09 \pm 36.35^{Aa}$	$2\,747.58 \pm 30.37^{ab}$	$2\,785.26 \pm 26.51^{b}$	$2\,815.27 \pm 27.18$
	Ⅲ	$2\,958.33 \pm 34.10^{Bb}$	$2\,769.15 \pm 52.56^{b}$	$2\,806.42 \pm 53.86^{b}$	$2\,830.33 \pm 32.09$

注：I=0g/d PRC；II=20g/d PRC；III=30g/d PRC

表 3 PRC 对围产期奶牛血浆代谢类激素指标的影响

Table 3 Effects of PRC on plasma metabolic hormone indices of periparturient dairy cows

项目 Items	组别 Groups	产前 7 天 7 days before parturition	产犊当日 Calving day	产后 7 天 7 days after parturition	产后 14 天 14 days after parturition
胰岛素 INS/(mIU/L)	Ⅰ	$15.30.40^{Aa}$	14.69 ± 0.51^{Aa}	13.37 ± 0.74	12.54 ± 1.54^{a}
	Ⅱ	17.43 ± 1.18^{ABb}	16.72 ± 0.91^{ABb}	14.96 ± 1.52	13.30 ± 0.96^{a}
	Ⅲ	19.60 ± 0.93^{Bc}	17.39 ± 0.88^{Bc}	15.85 ± 1.84	15.72 ± 0.60^{b}
胰高血糖素 GC/(pg/mL)	Ⅰ	285.96 ± 4.15	346.85 ± 4.49^{Aa}	387.30 ± 2.29^{Aa}	407.34 ± 4.27^{Bc}
	Ⅱ	283.13 ± 3.61	335.81 ± 4.84^{Ab}	361.40 ± 7.69^{Bb}	381.27 ± 6.16^{Ab}
	Ⅲ	278.41 ± 4.86	318.77 ± 5.80^{Bc}	344.24 ± 1.74^{Cc}	367.01 ± 6.80^{Aa}
瘦素 LEP/(ng/mL)	Ⅰ	5.08 ± 0.13^{a}	4.59 ± 0.09^{Bc}	4.90 ± 0.03^{a}	5.27 ± 0.05^{Bb}
	Ⅱ	4.78 ± 1.94^{ab}	4.38 ± 0.04^{ABb}	4.81 ± 0.10^{ab}	4.97 ± 0.08^{Aa}
	Ⅲ	4.52 ± 0.22^{b}	4.33 ± 0.09^{Aa}	4.71 ± 0.06^{b}	4.92 ± 0.08^{Aa}