

To study the importance of pyrroloquinoline quinone in pet nutrition and health care

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Abstract. Pyrroloquinoline quinone (PQQ) is a highly functional oxidoreductase coenzyme, which has a variety of physiological functions such as regulating the level of free radicals in the body, antioxidant and promoting nerve growth factor regeneration. PQQ plays a significant role in disease prevention and treatment, which has attracted wide attention in recent years. PQQ can protect the brain nerve and intestinal nerve of pets, reduce stress and anti-aging, and also promote nutrient absorption and improve immunity. Mammals can only take PQQ through external supplements and cannot synthesize it themselves. Therefore, the application of PQQ supplements in pet breeding can play a significant positive effect. Based on the studies supplementing PQQ in weaned rats and pigs, this paper will explain the necessity of PQQ for mammals, and discuss the feasibility of strengthening the use of PQQ supplement in pet nutrition and health care, and advocate further research on this by pet-related enterprises, which may open up new markets.

Keywords: Pyrroloquinoline quinone; Biological characteristics; Pet nutrition; Pet care.

1. Introduction to Pyrroloquinoline quinone

1.1. Chemical structure of Pyrroloquinoline quinone

Pyrroloquinoline quinone is a cofactor of methanol dehydrogenase^[1], a water-soluble quinone compound. Its molecular structure data and structural formula are shown in Table 1 and Figure 2. The molecular formula of Pyrroloquinoline is C₁₄H₆N₂O₈, the molecular weight is 330.206, the full English name is Pyrroloquinoline quinone, and the abbreviation is PQQ (note: the abbreviation of PQQ refers to pyrroloquinoline urea).

Table 1: Molecular structure data of pyrroloquinoline quinone

Molar refractive index	Molar volume(m ³ /mol)	Isotonic specific volume(90.2K)	Surface tension(dyne/cm)	polarizability(10 ⁻²⁴ cm ³)
71.98	168.2	573.1	134.8	28.53

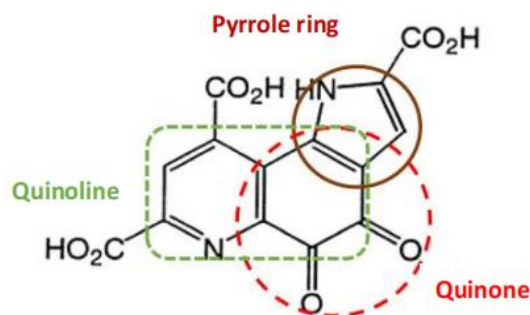


Figure 1: Chemical formula of pyrroloquinoline quinone

1.2. Discovery history and sources of pyrroloquinoline quinone

Prior to the appearance of PQQ, human beings had conducted considerable studies on the molecular structure, biochemical properties and biological effects of flavin nucleotides (FMN and FAD), dehydrogenase coenzyme nicotinamide nucleotides (NAD⁺ and NADP⁺), coenzyme Q, coenzyme A, etc. At present, flavin nucleotides have been found. The researchers also discovered a new class of dehydrogenase, glucose dehydrogenase, which depends on the activity of the new coenzyme and is present in the mammalian placenta lysine phthalein oxidase.

In nature, PQQ is currently believed that it is only produced in plants and other microorganisms other than G⁻, under the influence of Gram-negative bacteria (G⁻) synthesis after the decomposition of natural substances^[2].

1.2.1. Biosynthesis of PQQ

By using methyl trophotropic bacteria as the test strain in 1984 and raw silk microbacterium TKO441 as the production strain in 1992^[3], the way of generating PQQ in fermenter was established. The corresponding quinone protein of the bacteria synthesizing PQQ is shown in Table 2^[4].

Table 2: Bacteria that produce PQQ and their corresponding quinone proteins

Quinoprotein	Owning Bacteria
Methanol Dehydrogenase	Acetobacter methanolicus Methylotrophs
Ethanol Dehydrogenase	Pseudomonas aeruginase
Alcohol Dehydrogenase	Pseudomonas, Gluconobacter Acetobacter
Glucose Dehydrogenase	Acetobacter, Gluconobacter Pseudomonas, Klebsiella, Escherichia Coli PTS ⁻
Five Lobullar Dehydrogenase	Acinetobacter calcoaceticus
Polyvinyl alcohol Dehydrogenase	Pseudomonas
Polyethylene Glycol Dehydrogenase	Flavobacterium
Glycerol Dehydrogenase	Gluconobacter
Lupanine hydroxylase	Pseudomonas lupanini
Sorbitol Dehydrogenase	Gluconobacter suboxydans

1.2.2. Factors affecting PQQ biosynthesis

First of all, the precondition of PQQ biosynthesis is to screen and cultivate high-yield strains. The bacteria that synthesize PQQ use methanol as a carbon source. In nature, by the late exponential stage, methanol has almost been consumed, and malate dehydrogenase (MDH) is no longer necessary for bacterial survival in the case of PQQ dissociation when the enzyme is easily inactive^[5].

Some bacteria can produce excess PQQ (relative to the amount of enzyme protein) and secrete it outside the cell^[6]. These are PQQ high producing bacteria.

UAKRAMI et al.^[7] found that the concentration of Fe²⁺ had an effect on the yield of PQQ during fermentation with raw silk microbacteria TK0441. When the content of Fe²⁺ in the liquid culture substrate is decreased, the content of PQQ in the liquid culture will increase.

In addition, in the early stage of bacterial cultivation, the addition of a small amount of PQQ promoted the generation of PQQ^[8].

2. Biological characteristics and uses

2.1. Biological characteristics of PQQ

The biological effects of PQQ mainly focus on two aspects: First, PQQ plays an important role in the growth and development of mitochondria, which maintain the rapid growth of body cells; Second,

the oxidation resistance of PQQ is very good, and it can effectively remove free radicals. These two aspects of the role of PQQ brain, cardiovascular and metabolic aspects of the powerful function.

Since mammals cannot synthesize PQQ by themselves, it is generally necessary to extract it by fermentation from microorganisms and supplement it by grinding it into powder and taking it orally. The following takes the effect of “PQQ on the Morphological structure and neural function of duodenum in weaned rats” as an example to introduce the biological characteristics of PQQ in detail. We analyzed the necessity of supplementing PQQ in pet nutrition and health care combined with experimental data and results as follows.

2.1.1. As a cogroup of enzymes involved in life activities

PQQ plays an important role in the transfer of electrons, protons and chemical groups in many enzymatic reactions.

2.1.2. PQQ has a strong anticancer function

Studies have shown that PQQ can activate NK cells in the body, so that they have the ability to kill tumor cells. In addition, PQQ can also promote NK cells to cooperate with other immune cells to kill tumor cells more effectively^[9]. PQQ can also block the receptor of ferritin in tumor cells and prevent its further invasion^[10].

The most important thing is that PQQ has an effective role in preventing the occurrence of critical diseases such as tumors and heart disease.

2.1.3. Effective prevention of liver injury

Studies have shown that PQQ can significantly reduce the levels of serum bilirubin and glutamic-pyruvate transaminase, and has excellent curative effect on liver disease^[11].

2.1.4. Improve the immune function of the body

As an essential factor for the development of mammals, PQQ can activate the growth of B lymphocytes in the body^[12], which can produce antibodies and improve the immune function of the body.

2.1.5. As a growth factor or vitamin

PQQ can also be used as a growth factor for some bacteria^[13]. In addition, PQQ and its glycine adduct (OQP) have also shown important biological functions in mammals^[14].

2.2. PQQ acted on weaning mice and rats

It can be seen from the data that after oral administration of PQQ by laboratory mice, it passes through the small intestine and is excreted from the body through the kidneys within 24 hours, and can be rapidly absorbed. Such as PQQ lack of daily food feeding to mice, the mother mice have increased residual food phenomenon or newborn mice have stunted growth and development. In addition, young mice born will die due to weak skin and arterial tumors.

In addition, PQQ supplementation in mice can significantly increase the ratio of mitochondrial DNA/nuclear DNA in liver cells and the ratio of mitochondrial respiration in cardiomyocytes, which is conducive to repairing oxidative damage of myocardial mitochondria caused by ischemia-reperfusion^[15].

The trace presence of PQQ in animals and its important role in physiology suggest that it may be an important component of micronutrients in mammals^[16].

Shi Chenyu and Xu Song^[25] divided thirty Sprague Dawley rats into five groups, namely, basal (CTRL), basal plus LPS challenge (LPS), basal with 2.5 mg/kg b.w./day of PQQ plus challenge with LPS (PQQ 2.5), basal with 5.0 mg/kg b.w./day PQQ plus challenge with LPS (PQQ 5), and basal with 10.0 mg/kg b.w./day PQQ plus challenge with LPS (PQQ 10). They investigate the effect of pyrroloquinoline quinone (PQQ) on regulating neuropeptide secretion by ENS neurons of rats challenged with lipopolysaccharide (LPS) to create enteritis.

2.3. Effect of pyrroloquinoline quinone on pigs

2.3.1. Effect of PQQ on breeding sows

Xiao Junfeng ^[17] selected about 40 sows with a weight close to the thickness of the back, 90 days pregnant, 20 sows in each group, and randomly divided them into two groups. The experimental groups were supplemented with vitamin E60 mg/kg and organic selenium 0.20 mg/kg in the basal diet, and the experimental groups were supplemented with organic selenium 1mg/kg PQQ in the basal diet. The test was conducted on the 7th day after pregnancy. Compared with the control group, dietary addition of PQQ had no significant effects on the delivery course, litter size, live litter size and piglets of sows with average weight of first born piglets and average weight of daily gaining piglets of 7 days ($P>0.05$), but the values were increased.

Dietary PQQ supplementation significantly increased the serum total superoxide dismutase and reduced glutinergin contents of newborn piglets and sows ($P < 0.05$), while dietary PQQ supplementation significantly decreased the serum malondialdehyde content of pigs ($P<0.05$). However, there were no significant effects on the activity, total antioxidant capacity and content of serum dioxygenase ($P>0.05$) in experimental group.

In conclusion, in the perinatal diet, the serum antioxidant function of PQQ has a significant enhancement effect on the perinatal sows and piglets shortly after birth.

2.3.2. Effect of PQQ on weaned piglets

Weaning results in changes in nutrient sources, impaired digestion and immune function of piglets, which often result in growth inhibition and high incidence of diarrhea, which has a serious impact on the growth and development of piglets.

Jarat et al. ^[18] studied the effects of different grades of PQQNa₂ added to the feed of weaned piglets on the growth performance and intestinal development of piglets, and found that PQQ disodium salt can effectively improve the weight gain and feed conversion rate of piglets, and significantly reduced the diarrhea rate and various inflammatory factors levels.

Other studies on the effects of PQQ on piglets are presented in Table 3.

Table 3: Literature on the effects of pyrroloquinoline quinone on piglets in the last decade^[25-28]

<u>PQQ·Na₂, mg/kg</u>	<u>Effects on piglets</u>	<u>Author</u>
<u>1.5</u>	Increase of daily feed intake and daily weight gain in lactating pigs	<u>Song zhuang, 2013</u>
<u>1.5, 3.0, 4.5</u>	Improve the growth period and antioxidant capacity of intestine and liver	<u>Fan zijuan, 2013</u>
<u>0, 1.5, 3.0, 4.5, 6.0, 7.5</u>	<u>Reduce the rate of diarrhea, reduce intestinal mucosal oxidation and inflammatory factors</u>	<u>Yin Xindi, 2019</u>
<u>3.0</u>	The imbalance of microflora in piglet colon was improved after E. coli challenge	<u>Huang caiyun, 2020 and 2021</u>
	Inhibit NF-B pathway and promote jejunal mucosa recovery after inflammatory injury	<u>Huang caiyun, 2021 and 2021</u>
<u>7.5, 75.0</u>	High dose of PQQ·Na ₂ did no harm to weaned piglets	<u>Ming Dongxu, 2021</u>

2.4. The importance and feasibility of PQQ in pet health care

2.4.1. The importance of PQQ in pet care

Nutrition and health are vital to a pet's life. People often use food and supplements to help their pets maintain a healthy physical condition. As technology continues to evolve, more and more research is being done to develop new methods and products to improve the health of pets.

Studies have shown that pyrroloquinoline quinone has a variety of antioxidant, anti-inflammatory and immunomodulatory effects, and has potential benefits for pet health. At the same time, PQQ has a good safety and biodegradable, not excessive degree will not cause any adverse effects on the pet's body.

For cats, dogs and other pets, PQQ plays a significant role in the biological functions of mitochondrial generation, cell signal transduction, energy metabolism, growth stimulation, DNA repair, promotion of mitochondrial generation, improvement of energy metabolism, anti-oxidation, promotion of growth and reproduction, immune regulation and anti-inflammatory, anti-stress, nerve protection and other biological functions in various studies.

The use of pyrroloquinoline quinone in pet health care has been supported by some studies. Sakurai T et al. [19] found that pyrroloquinoline quinone can enhance cat immune system function by increasing serum total antioxidant capacity and reducing glutathione level. In addition, pyrroloquinoline quinone can also reduce the white blood cell count and C-reactive protein levels in the serum, thereby reducing the inflammatory response. One study also found that PQQ can prevent malignant tumors in certain dog breeds by inhibiting tumor cell growth and inducing tumor cell apoptosis.

Kim HY et al. [20] found that pyrroloquinoline quinone can improve heart function in pet cats and dogs. The study, which involved 80 cats and dogs over the age of one, found that PQQ significantly improved the pets' heart output, left ventricular systolic blood pressure and myocardial contractility. These results suggest that PQQ plays an important role in pet heart health.

In addition to this, some studies showed that pyrroloquinoline quinone could help pet cats and dogs relieve stress and anxiety, improve skin health, increase appetite and improve digestion, among other things [26-30]. These results indicate that pyrroloquinoline quinone has a wide application prospect in pet health care.

However, pet nutritional supplements focusing on PQQ on the market are very few or almost not applied, PQQ in the "hair cream", "nutrition cream" and other common pet health food popularity is very low, and the application of pyrroloquinoline quinone is not limited by age, gender and breed, has great benefits for pets, suitable for all pet cats and dogs. Therefore, it is important to promote the application of PQQ in pet health care.

2.4.2. Feasibility of PQQ in pet health care

Kondo et al. [21] experimented with a group of pet cats by adding pyrroloquinoline quinone to their diets. Compared to the control group that did not receive PQQ, the pet cats in the experimental group that received PQQ showed better physical condition, including healthier coats and stronger immune systems. This study shows that PQQ can be used as a safe and effective pet health product.

It should be noted that although pyrroloquinoline quinone is considered a natural compound, it still needs to be used with caution. Before applying pyrroloquinoline quinone, a veterinary professional should first be consulted to ensure that pets do not have allergic reactions or adverse reactions to the compound. In addition, attention should be paid to the dosage and method of use to avoid any negative effects.

In conclusion, as a potential pet health care product, pyrroloquinoline quinone has great feasibility and necessity. Future research will further explore the application of pyrroloquinoline quinone to help pets maintain a healthy physical condition.

In the process of pet raising, the pet staple food industry has an updated and iterative trend in its development. The problems related to staple foods, upgrading of ingredients and new nutritional additions are worthy of the attention of the pet health industry and pet owners.

According to Yan Li's research literature^[22], with the upgrading of new consumption and the concept of scientific pet keeping, more and more consumers pay attention to the nutrition and health of pets.

According to the "Pet White Paper" ^[23], in terms of pet nutrition and health needs, pet owners choose "dietary supplements - such as freeze-dried homemade vegetables or offal meat", "nutritional formula food" and other programs to supplement pet nutrition every day. The addition of PQQ in pet diets is in line with the expectations in the "White paper", and meets the needs of pet owners for comprehensive and balanced nutrition and health care of their pets.

Video promotion apps such as XiaoHongshu, Douyin and Bilibili, pet bloggers and nutrition advocacy researchers have promoted PQQ as a powerful antioxidant in the body. For example, a user in the XiaoHongshu app, "The dog eggs of the urban and rural connection Department," posted: Their pet blue cat has been 8 years old, which is equivalent to 48 years old in human terms. The pet owner said that in addition to daily grooming, body massage, and annual physical examination, he felt that the anti-aging and maintenance links of pets needed to pay attention to were diet and health care, and in addition to common health products such as probiotics, hair cream, hair powder, and joint tablets. The authors also mention a product "GNC Rejuvenation Stick NMN", which is a pet health product jointly developed by Pet Citizens and GNC Grand Works. The main ingredients are β -NMN, trans-resveratrol and pyrroloquinoline quinone. β -NMN is the precursor of NAD⁺. Because the molecular weight of NAD⁺ is too large to be directly supplemented to pets, it should be supplemented by feeding β -NMN. For pet cats, trans-resveratrol is more conducive to the absorption of pet body than cis, which can activate the longevity protein in pet body together with NMN; In addition, PQQ is also strongly recommended by users of this product due to its high safety, stable effect of increasing the number of mitochondria, and excellent anti-aging effect.

Based on these data, I believe that it is feasible to further promote PQQ nutritional supplements as pet health products.

2.5. Application of PQQ in pet health care

According to the biological characteristics of PQQ, the supplement of PQQ can bring multiple benefits in terms of pet nutrition and health care. Through experimental and clinical observation, PQQ can help pets maintain health, enhance immune function, and prevent Alzheimer's disease and cardiovascular disease.

2.5.1. Help keep your pet healthy

As a nutritional supplement, PQQ can improve the energy level of the pet body, and improve the metabolism and immune function of pets by maintaining mitochondrial growth and development and antioxidant effects.

2.5.2. Enhance immune function

PQQ can also help the body to remove free radicals and harmful substances, reduce damage to cells, and thus enhance the immune function of the pet body.

2.5.3. Prevent Alzheimer's and cardiovascular disease

PQQ's antioxidant properties can help pets to prevent age-related diseases such as Alzheimer's and cardiovascular disease. It can help pets maintain cardiovascular health and the normal function of the nervous system by inhibiting the generation of free radicals and removing harmful substances.

3. Conclusion

Pet cats and dogs have been treated as family members nowadays, and their health and well-being have become the focus of attention. With the development of pet health care industry and the in-depth research in the field of medicine, the application of natural herbs in pet health care has attracted more and more attention. Pyrroloquinoline quinone is a natural herb that has been shown to have a wide

range of pharmacological effects. This paper discusses the feasibility and necessity of pyrroloquinoline quinone in pet cat and dog health care, and provides related research support.

Major experiments and research reports have shown that pyrroloquinoline quinone is an indispensable trace compound for mammals. The experiments I participated in also demonstrated the application of pyrroloquinoline quinones in animal husbandry by exploring the effects of PQQ on the morphology and nerve function of the duodenum of weaned rats, and the effects of PQQ on the intestinal and cranial nerves of weaned piglets.

In summary, pyrroloquinoline quinone is feasible and necessary in pet cat and dog health care. PQQ has a variety of pharmacological effects, can provide comprehensive health care services for pets, and is safe and biodegradable^[24]. Although the application of pyrroloquinoline quinone in pet health needs more research support, the existing research results show that pyrroloquinoline quinone has a wide range of application prospects. Therefore, it is recommended that pyrroloquinoline quinone has been promoted to the market as a new pet health care herb to provide better nutritional health care options for more pets.

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