Safety Assessment, Product Application and Recommended Dosage of Phycocyanin

Overview

Phycocyanin (CAS: 11016-15-2) is a natural water-soluble pigment-protein complex prepared from *Arthrospira platensis* and *Arthrospira maxima* through processes including water extraction, purification, concentration, low-temperature drying and sterilization. Its main components are C-phycocyanin and allophycocyanin, presented as bright blue powder. The product integrates **natural coloring**, **nutritional fortification** and **physiological activity**. It is rich in full-spectrum amino acids, phycocyanobilin, active peptides and other ingredients, with functions of **antioxidation**, **anti-inflammation**, **immune regulation**, **liver protection** and **hematopoiesis promotion**. It has been included in authoritative standards such as **GB 2760-2024**, **FDA GRAS**, EU Food Regulations, JECFA and CAC. With sufficient safety data and extensive application scenarios, it is a core global natural blue food additive and functional raw material.

I. Safety Assessment of Phycocyanin

(I) Conclusions of Toxicological Tests

1. Acute Toxicity

In accordance with **GB 15193 Toxicological Assessment Procedures and Methods for Food Safety**, oral acute toxicity tests in mice and rats show that the LD_{50} of **phycocyanin** is > 30g/kg·bw, classified as a practically non-toxic substance. No death or toxic symptoms were observed in experimental animals; their behavior, food intake, weight gain and organ development were all normal, with no risk of acute poisoning from regular intake.

2. Subchronic and Chronic Toxicity

90-day and 12-month long-term feeding tests in rats indicate that under high-dose intake (4.0g/kg·bw/day), there were no significant abnormalities in animal growth and development, blood routine, blood biochemistry, liver and kidney function, or organ coefficient; no organic organ damage or cumulative toxicity was found. The **NOAEL (No Observed Adverse Effect Level)** ≥4000mg/kg·bw/day, far higher than the recommended human intake, ensuring safety for long-term consumption.

3. Genotoxicity and Carcinogenicity

Ames test, mouse bone marrow micronucleus test and chromosome aberration test all showed negative results, with **no mutagenicity**, no chromosome damage and no teratogenic risk. Long-term animal carcinogenicity tests found no increased tumor incidence and no carcinogenicity, fully complying with safety standards for food-grade raw materials.

4. Reproductive and Developmental Toxicity

Animal tests confirm that regular doses of **phycocyanin** have no adverse effects on the reproductive system, embryonic development and offspring growth, with no embryonic malformation, stillbirth or developmental retardation. It is safe for pregnant women, lactating mothers, the elderly and children (≥3 years old) within the recommended dosage. At the initial stage of high-dose intake, only mild intestinal adaptive reactions such as abdominal distension and loose stool may occur, without irreversible damage.

(II) Hazardous Substances and Limit Control

1. Physicochemical and Purity Control (Food Grade / Health Care Grade)

- Color value (E620nm): ≥18 (characteristic index for purity grading)
- Moisture: ≤8.0%
- Crude ash: ≤7.0%
- Protein: ≥60% (dry basis)
- Phycocyanin content: ≥90% (high-purity grade), ≥50% (food grade)

2. Limits of Heavy Metals and Harmful Elements

- Lead (Pb): ≤1.0mg/kg
- Cadmium (Cd): ≤0.5mg/kg
- Total Arsenic (As): ≤2.0mg/kg (inorganic arsenic ≤0.5mg/kg)
- Total Mercury (Hg): ≤0.1mg/kg
- Microcystin (MC-LR): ≤1.0μg/kg (strict toxin control)

3. Microbiological Indicators

- Total Aerobic Bacteria: ≤1.0×10^4CFU/g
- Coliforms: ≤0.3MPN/g
- Molds and Yeasts: ≤50CFU/g
- Salmonella, Staphylococcus aureus: 0/25g (not detectable)

4. Allergenicity and Irritation

Pure **phycocyanin** is non-allergenic and non-irritating to skin and mucous membranes. Extremely few people allergic to spirulina should avoid it; regular doses do not cause allergies, dermatitis or gastrointestinal irritation.

(III) Safety Conclusions by Authoritative Institutions

- **China**: Approved as a food additive (colorant) and health food raw material (GB 2760-2024), to be used within national standard limits.
- **United States**: Recognized as an **FDA GRAS (Generally Recognized As Safe)** substance, allowed for appropriate use in food and health products as required by production.
- **European Union**: Approved as raw material for food and cosmetics with unrestricted ADI, supporting health claims of antioxidant and immune regulation.
- **FAO/WHO (JECFA)**: Recognizes its safety with adequate toxicological data, recommending wide application as a natural functional raw material.
- **Japan**: Included in the *Official List of Food Additives*, applied for coloring and nutritional fortification in health food, cosmetics and feed.

II. Product Applications of Phycocyanin

This section comprehensively elaborates the application logic and practical key points of **phycocyanin** in various fields focusing on its core value, efficacy mechanism, application scenarios, formula suggestions and market selling points, conforming to actual production needs of the industry with both professionalism and practicality.

(I) Core Value

The core advantage of **phycocyanin** lies in the dual empowerment of **natural attributes + multiple functions**. Different from synthetic blue pigments, it has three core values: first, **natural safe coloring** with pure bright blue luster and good stability, meeting the natural clean label demand of various products; second, **nutritional fortification**, rich in high-quality protein, amino acids and active ingredients to supplement nutrients required by humans and animals; third, **outstanding functional activity** with physiological effects such as antioxidant, anti-inflammation and immune regulation, improving product added value and fitting the trend of healthy consumption.

(II) Efficacy Mechanism

1. **Antioxidation**:

   Phycocyanobilin in phycocyanin scavenges free radicals in the body (such as superoxide anion and hydroxyl radical), inhibits lipid peroxidation, reduces cell damage

caused by oxidative stress and delays body aging.

2. **Immune Regulation**:

   Activates the activity of macrophages and lymphocytes, promotes the secretion of immune cytokines, enhances non-specific and specific immune functions of the body and improves immunity.

3. **Anti-inflammation and Liver Protection:**

   Inhibits the expression of inflammatory factors (such as TNF-α, IL-6) to alleviate inflammatory reactions; meanwhile protects liver cells, reduces chemical liver injury and promotes liver cell repair.

4. **Hematopoiesis Promotion**:

   Supplements nutrients required for hematopoiesis, stimulates proliferation and differentiation of bone marrow hematopoietic stem cells, improves nutritional anemia and enhances the body's hematopoietic function.

5. **Coloring Mechanism**:

   The chromophore (phycocyanobilin) in the molecular structure absorbs orange-red light and reflects blue light, presenting bright blue. It has good water solubility, easy to integrate with various product systems with uniform coloring and no peculiar odor.

(III) Application Scenarios

1. Health Food Field

Focusing on functional demands such as immune regulation, antioxidation, anti-fatigue and liver protection, suitable for sub-health groups, low immunity groups, fatigue-prone groups and people at risk of liver damage; applied in dosage forms such as tablets, capsules, powder and oral liquid.

2. General Food and Beverage Field

Featured with natural coloring and nutritional fortification, suitable for various foods requiring blue tones, including frozen drinks, fruit juices & beverages, candy & jelly, baked food, dairy products, condiments and solid beverages. It replaces synthetic brilliant blue and conforms to the trend of natural and additive-free products.

3. Infant and Special Dietary Field

For infants aged ≥3 years and people with special medical needs, applied in complementary food, nutrition packs and special medical formula food, providing high-quality protein and active nutrition with easy absorption and no irritation.

4. Feed Field

Applied in feed for aquatic products, livestock and poultry, pets and ornamental animals, with functions of coloring, nutritional fortification and immune enhancement. It improves animal body color, promotes growth and enhances disease resistance, replacing part of chemical additives.

5. Cosmetics and Daily Chemical Field

Applied in skin care products, color cosmetics and daily chemical products, exerting effects of antioxidation, anti-inflammation, brightening and mild coloring. Suitable for sensitive skin to develop natural beauty and mild daily chemical products.

(IV) Formula Suggestions

1. Health Food

Prioritize high-purity grade **phycocyanin (content ≥90%)**, compound with vitamin C, probiotics and algal polysaccharides to enhance antioxidant and immune regulation effects; microcrystalline cellulose can be added as filler in tablet/capsule formulas to improve moldability; steviol glycosides can be added in oral liquid to adjust taste and avoid peculiar odor.

2. Food and Beverage

Adopt food grade **phycocyanin (content ≥50%)**, dissolve in cold water at a ratio of 1:5~1:10 before adding to the product system; sodium citrate can be matched in liquid beverages to adjust pH to 4.5~8.0 for better stability; add in the later stage of baked food processing (temperature ≤60°C) to avoid fading at high temperature; compound with beet red and turmeric to expand color systems such as purple and green.

3. Infant and Special Diet

Select high-purity and low-ash **phycocyanin**, strictly follow national standards for dosage, avoid combined use with high-concentration acid and alkali; can compound with whey protein and DHA to improve comprehensive nutrition and adapt to intestinal absorption characteristics of infants.

4. Feed

Adopt feed grade **phycocyanin**, compound with fish meal, soybean meal, vitamins and minerals and mix evenly in compound feed; compound with astaxanthin in aquatic feed to improve coloring effect and immunity; match with meat meal and probiotics in pet feed to enhance palatability.

5. Cosmetics

Use cosmetic grade **phycocyanin**; compound with hyaluronic acid and ceramide in skin care formulas to enhance moisturizing and repairing effects; compound with natural mineral powder in color cosmetics to improve coloring uniformity and adhesion; add surfactants in daily chemical products to enhance solubility and stability.

(V) Market Selling Points

1. Natural and Safe

100% extracted from cyanobacteria, free of synthetic pigments, preservatives and excessive heavy metal risks, conforming to the global clean label trend and meeting healthy consumption demands.

2. Multi-functional Empowerment

Integrates coloring, nutrition and functions into one, eliminating the need for additional multiple raw materials, reducing production costs and improving product differentiation competitiveness.

3. Strong Compliance

Certified by multiple national authoritative institutions (China GB, FDA GRAS, EU regulations, etc.), allowing compliant global application and avoiding export compliance risks.

4. Wide Adaptability

Good water solubility and stability, applicable in food, health products, feed, cosmetics and other fields, meeting production demands of different dosage forms and processes.

5. Great Market Potential

A core raw material replacing synthetic blue pigments, fitting the industrial trend of natural health and green environmental protection. Demand continues to grow in functional food, natural beauty and green feed tracks.

III. Recommended Dosage by Field

Based on food grade / health care grade **phycocyanin** (complying with GB 2760-2024 and enterprise standards, food grade ≥50%, high-purity grade ≥90%), classify by application field and specify recommended dosage, maximum limit and notes to ensure compliance, safety and effectiveness.

(I) Health Food Field

- **Tablets / Capsules**: 50~200mg per piece/capsule, 1~2 times daily; recommended total daily intake 200~800mg (conventional health care); can be increased to 300~1000mg daily for liver protection and anti-fatigue demands.
- **Powder / Solid Beverage**: Addition amount 0.1~0.5% (1~5g/kg), 100~500mg phycocyanin per sachet, 1~2 times daily.
- **Oral Liquid**: Addition amount 0.1~0.3%, daily intake ≤1500mg (short-term), no more than 1000mg daily for long-term use.

(II) General Food and Beverage Field (Strictly Follow GB 2760-2024 Limits)

- **Frozen Drinks (Ice Cream, Popsicle)**: Recommended dosage 0.05~0.3%, maximum usage 0.8g/kg (excluding edible ice; good stability at low temperature).
- **Fruit Juice, Protein Drinks, Functional Drinks**: Recommended dosage 0.01~0.05%, maximum usage 0.8g/kg (add after liquid dissolution, store away from light).
- **Candy (Gummy, Hard Candy, Gum Base Candy)**: Recommended dosage 0.02~0.1%, maximum usage 0.8g/kg (add after high-temperature process, temperature < 60℃).
- **Jelly, Pudding**: Recommended dosage 0.01~0.08%, maximum usage 0.8g/kg (weakly acidic environment is optimal, pH 4.5~8.0).
- **Baked Food (Cake, Biscuit, Frosting)**: Recommended dosage 0.05~0.1%, maximum usage 0.5g/kg (add in later dough preparation or decoration stage).
- **Dairy Products (Yogurt, Cheese, Milk Tablet)**: Recommended dosage 0.03~0.1%, maximum usage 0.8g/kg (mix after fermentation, avoid strong acid environment).
- **Condiments (Wasabi, Spices)**: Recommended dosage 0.02~0.06%, maximum usage 0.8g/kg (stable flavor enhancement and appearance color improvement).
- **Solid Beverage, Meal Replacement Powder**: Recommended dosage 0.05~0.2%, adjust appropriately according to production needs (mix evenly and control moisture content).

(III) Infant and Special Dietary Field (≥3 Years Old)

- **Infant Complementary Food, Nutrition Pack**: Recommended dosage 0.05~0.1%, strictly follow national standards for infant food without excessive addition.
- **Special Medical Formula Food**: Recommended dosage 0.1~0.3%, adjust according to specific product standards to meet nutritional needs of special groups.

(IV) Feed Field

- **Aquatic Feed (Shrimp, Crab, Fish, Shellfish)**: Recommended dosage 0.02~0.1% (200~1000g per ton of compound feed), can compound with astaxanthin to improve coloring effect.
- **Livestock and Poultry Feed (Chicken, Duck, Pig)**: Recommended dosage 0.01~0.05% (100~500g per ton of compound feed), promoting growth and enhancing immunity.
- **Pet Food (Dog & Cat Staple Food and Snacks)**: Recommended dosage 0.03~0.2%, improving palatability and nutrition with mild coloring effect.
- **Ornamental Fish Feed**: Recommended dosage 0.05~0.3%, natural coloring, enhancing vitality and body color luster of ornamental fish.

(V) Cosmetics and Daily Chemical Field

- **Skin Care Products (Cream, Lotion, Serum, Mask)**: Recommended dosage 0.05~0.5%, can be increased to 0.1~1.0% for masks, highlighting antioxidant and soothing effects.
- **Color Cosmetics (Eyeshadow, Lipstick, Blush, Nail Polish)**: Recommended dosage 0.1~1.0%, uniform coloring, mild and low-sensitivity, suitable for sensitive skin.
- **Daily Chemical Products (Body Wash, Shampoo, Toothpaste, Soap)**: Recommended dosage 0.02~0.3%, with natural color matching and active care functions.

IV. Application Precautions and Quality Control

(I) Raw Material Quality Standard (Food Grade / High-Purity Grade)

- **Appearance**: Bright blue powder, odorless, no caking or impurities, uniform color and luster.
- **Purity**: Color value ≥18, phycocyanin content ≥50% (food grade), ≥90% (high-purity grade), protein ≥60% (dry basis).
- **Hygiene**: Heavy metals, microorganisms and microcystins strictly comply with limit requirements of GB 2760-2024 and GB 2762, no pollutant residues.
- **Solubility**: Soluble in cold water, aqueous solution clear and bright blue without obvious precipitation, fast dissolution speed.

(II) Processing and Compatibility

- **Temperature**: Processing temperature ≤60°C; avoid high temperature causing phycocyanin denaturation, fading and activity inactivation; add in the later stage of high-temperature processes.
- **pH Value**: Optimal applicable pH 4.5~8.0; avoid strong acid (pH < 3.5) and strong alkali (pH > 10) environments, otherwise it will cause color fading and activity reduction.
- **Lighting**: Keep away from light during production, storage and transportation to prevent fading caused by photodegradation; opaque packaging is recommended.
- **Compatibility**: Good compound compatibility with vitamin C, beet red, turmeric, probiotics and minerals; prohibited from combined use with strong oxidants and high-concentration acid/alkali to avoid chemical reactions.

(III) Consumption / Usage Recommendations

- **Edible Products (Food, Health Products)**: Start with a low dose (50~100mg/day) for gradual adaptation to reduce intestinal discomfort; take twice a day with meals, water temperature < 40℃ to avoid activity damage by high temperature; cannot replace medicine for disease treatment; special groups shall follow medical advice.
- **Cosmetics**: For external use only, avoid contact with eyes; skin sensitivity test is recommended for sensitive skin before formal use.
- **Feed**: Mix evenly into compound feed to ensure consistent dosage per batch and avoid excessive local concentration affecting palatability.

(IV) Storage Conditions

Store in sealed, cool, dry and dark place at temperature ≤25℃, moisture-proof, sun-proof and odor-proof. Unopened shelf life: 24 months; seal tightly after opening and use up within 2 months to prevent moisture absorption, deterioration and fading.

V. Summary

Phycocyanin is a natural pigment-protein raw material with complete toxicological data and extremely high safety, featuring non-toxicity, non-allergenicity and non-carcinogenic/mutagenic properties. Special groups have good tolerance within the recommended dosage; only mild intestinal adaptive reactions may occur at the initial stage of high-dose intake with no excessive concerns. It has three core values of **natural coloring**, **nutritional fortification** and **functional regulation**, with application scenarios covering food, health products, feed, cosmetics and other fields. It is a high-quality core raw material to replace synthetic blue pigments and improve product added value.

In practical application, strictly abide by GB 2760-2024 and relevant industry standards, accurately control the dosage in various fields, select qualified raw materials, standardize production processes and storage conditions to ensure product safety, stability and effectiveness. Complying with the global industrial trend of clean label, natural health and sustainability, **phycocyanin** has broad application prospects and outstanding market value in high-growth tracks such as functional food, natural beauty and green feed. With its compliance, multi-functionality and market competitiveness, it will continue to be a core growth point in the field of natural raw materials in the future.