Unique Performance Analysis of Calcium Citrate

Calcium Citrate (CAS No.813-94-5, Tricalcium Citrate Tetrahydrate, E333) is an **internationally recognized high-quality organic calcium nutritional fortifier**. It is certified by authoritative standards including **GB 1903.14-2016 of China, FDA GRAS, JECFA and EFSA**. Featuring core advantages of **non-gastric-acid-dependent absorption, high bioavailability, mild low irritation and multi-scenario process compatibility**, it comprehensively solves industrial pain points of traditional inorganic calcium such as calcium carbonate and calcium phosphate, as well as conventional organic calcium including calcium gluconate and calcium lactate, such as limited absorption, gastrointestinal irritation, unstable processing performance and dietary antagonism. It provides an **efficient, safe, mild and globally compliant systematic solution** for calcium nutrition supplementation for infants, pregnant and lactating women, middle-aged and elderly groups, people with insufficient gastric acid, as well as the food industry, pharmaceutical health care and special dietary fields.

I. Physicochemical Characteristics

1. Basic Physicochemical Parameters

- **Official Chemical Name**: Tricalcium Citrate Tetrahydrate (2-Hydroxypropane-1,2,3-tricarboxylic acid calcium tetrahydrate)
- **Structural Formula**: \(\ce{Ca3(C6H5O7)2\cdot 4H2O}\)
- **Molecular Formula**: \(\ce{C12H10Ca3O14\cdot 4H2O}\)
- **Exact Molecular Weight**: 570.50
- **Theoretical Calcium Content**: 21.08%
- **Commercial Grade Calcium Content**: 20.5% ~ 21.5% (dry basis, complying with GB 1903.14-2016)
- **Appearance Properties**: White to off-white crystalline powder, **odorless, tasteless and without metallic astringency**
- **Solubility Index**:

▲ Solubility in pure water at 25℃: 0.095 g/100 mL (slightly soluble; solubility significantly increased in acidic environment)

▲ Freely soluble in dilute hydrochloric acid, dilute nitric acid and citric acid solution; soluble **without reliance on strong gastric acid**

▲ Practically insoluble in organic solvents such as ethanol, ether and acetone

- **Aqueous Solution pH Value** (1% suspension, 25℃): 6.0 ~ 7.5, **near-neutral system**, compatible with weakly acidic, neutral and weakly alkaline food substrates
- **Bulk Density**: 0.55 ~ 0.70 g/cm³, good powder fluidity, easy to blend and not easy to delaminate

- **Particle Size Index**: 95% passes through 200-mesh standard sieve, suitable for dry mixing, wet batching, spray drying and other processes
- **Hygroscopicity**: Slightly hygroscopic, prone to caking in high humidity environment; required to be hermetically sealed for moisture-proof storage in cool and dry places

2. Stability Characteristics

- **Molecular Structural Stability**: Citrate ions form a **stable complex structure** with calcium ions, which will not dissociate in gastric acid environment (pH 1.5 ~ 3.0) and release **no free calcium ions**, avoiding gastrointestinal irritation.
- **Thermal Stability**: Physically and chemically stable below 120℃; gradually loses crystal water at 100℃ and completely dehydrates into anhydrate at 125℃. Tolerates conventional food processes including spray drying, UHT sterilization, pasteurization, baking and extrusion puffing.
- **Oxidation Stability**: Inert in chemical properties; no oxidation or discoloration under normal temperature and pressure, and does not catalyze oxidative rancidity of vitamins, oils and pigments in food systems.
- **Acid-Base Tolerance Stability**: Stably adapts to a wide pH range of 3.0 ~ 10.0, suitable for full scenarios including acidic beverages, neutral dairy products, alkaline grain products and solid beverages.
- **Chemical Compatibility Stability**: No precipitation or antagonism when coexisting with phytic acid, tannic acid, oxalic acid and dietary fiber; no nutritional competition with minerals such as iron, zinc, magnesium and selenium, enabling **synergistic absorption**.
- **Shelf Storage Stability**: Under sealed, light-proof conditions with relative humidity ≤60%, the shelf life is 24 months, with no obvious attenuation in color, fluidity and calcium content.

3. Authoritative Safety Parameters

- **Chinese National Standard Basis**: GB 1903.14-2016 *National Food Safety Standard – Food Nutrient Fortifier – Calcium Citrate*; Nutrient fortification follows GB 14880-2012.
- **International Authoritative Certification**: FDA GRAS (Generally Recognized As Safe), JECFA (no specific limit on ADI), EFSA, EU E333 and CAC standard approval.
- **Toxicological Safety**: Acute oral LD_{50} > 10 g/kg, classified as practically non-toxic; no genotoxicity, teratogenicity, carcinogenicity or reproductive toxicity.
- **Heavy Metal Limits**: Lead ≤2.0 mg/kg, Arsenic ≤3.0 mg/kg, Fluoride ≤30 mg/kg, exceeding the international pharmacopoeia standards of USP and EP.

- **Population Applicability**: Safe for long-term consumption by infants, pregnant women, lactating women, the elderly, people with insufficient gastric acid and those taking long-term acid inhibitors.

II. Functional Characteristics (Core Performance Comparison with Traditional Calcium Sources)

1. Comparison of Absorption Mechanism and Bioavailability

- **Calcium Carbonate (Inorganic Calcium)**: Relies heavily on gastric acid for dissolution; low absorption rate on an empty stomach (about 15% ~ 20%); rises to 25% ~ 30% when taken with meals; strongly inhibited by phytic acid and tannic acid.
- **Calcium Lactate / Calcium Gluconate (Conventional Organic Calcium)**: Good water solubility but **low calcium content** (18.3% for calcium lactate, 9.3% for calcium gluconate); absorption rate about 20% ~ 25%, still affected by gastric acid and dietary factors.
- **Calcium Citrate (High-Quality Organic Calcium)**: Absorption independent of gastric acid; stable absorption rate of 25% ~ 35% both on an empty stomach and with meals; **22% ~ 27% higher than calcium carbonate**; resistant to dietary antagonism with dual absorption pathways of intestinal active transport and passive diffusion.

2. Comparison of Gastrointestinal Tolerance and Side Effects

- **Calcium Carbonate**: Neutralizes gastric acid, causing flatulence, constipation and belching; long-term intake increases the risk of kidney stones; unsuitable for people with insufficient gastric acid, weak gastrointestinal function and the elderly.
- **Calcium Lactate**: Mild in nature but long-term intake easily causes lactic acid accumulation, muscle soreness and fatigue.
- **Calcium Citrate**: Near-neutral property with no free calcium; no gas production, no gastric mucosal irritation and no disruption of intestinal osmotic pressure; almost no constipation, bloating or nausea; citrate inhibits calcium oxalate crystallization and reduces kidney stone risk.

3. Comparison of Process Adaptability and Sensory Properties

- **Calcium Carbonate**: Poor water solubility, easy precipitation and delamination with rough taste; prone to discoloration at high temperature and damage to product appearance.
- **Calcium Lactate / Calcium Gluconate**: Good water solubility but strong hygroscopicity, easy caking and short shelf life; low calcium content requiring large addition dosage and high formula cost.

- **Calcium Citrate**: Slightly soluble but rapidly soluble in acidic environment; stable powder with good fluidity and uniform mixing performance; **odorless, non-coloring and non-precipitating**, without affecting product flavor and appearance; high temperature resistance, acid-base resistance and storage stability.

III. Summary of Core Unique Performances

1. Non-Gastric-Acid-Dependent High-Absorption Calcium Source

The complex structure enables direct dissolution without gastric acid activation, maintaining consistent absorption rate on an empty stomach and after meals. Its bioavailability is **22%～27% higher** than calcium carbonate, realizing **low dosage and high absorption**. It is especially suitable for the elderly, people with insufficient gastric acid and long-term acid inhibitor users.

2. Zero-Gastrointestinal-Irritation Mild Calcium Source

Near-neutral molecular property with no free calcium ions; no gastric mucosal corrosion, no flatulence or constipation, and no metallic odor. Well tolerated by all populations, it serves as a dedicated safe calcium source for infants, pregnant and lactating women, postoperative rehabilitation crowds and people with gastrointestinal diseases.

3. Wide Process Adaptability & Full-Scenario High Stability

Heat-resistant (≤120℃), acid-base resistant (pH 3.0 ~ 10.0), oxidation-resistant and storage-resistant. Compatible with full processes including liquid beverage production, solid powder preparation, baking, extrusion and sterilization; no discoloration, no precipitation and no damage to product sensory quality.

4. Dietary Antagonism Resistance & Multi-Mineral Synergy

No complex precipitation with phytic acid, tannic acid, oxalic acid and dietary fiber; no nutritional antagonism with iron, zinc, magnesium and selenium, supporting the demand for compound mineral nutritional fortification.

5. Global Compliance & Multi-Field Versatility

Compliant with authoritative standards including Chinese GB, FDA, JECFA, EFSA and EU E333. Universally applicable for domestic and export sales with full access to special dietary products, without compliance barriers.

IV. Commercial Value

1. Premium Product Quality Premium

Odorless, non-discoloring, non-precipitating and gastrointestinal-friendly. It helps develop high-end products such as infant complementary foods, prenatal and lactation nutrition products, middle-aged and elderly health foods and plant-based beverages, boosting market premium by **more than 30%** and enhancing brand competitiveness.

2. Precise Formula Cost Optimization

Benefiting from high bioavailability, the required dosage is reduced by **25% ~ 40%** compared with calcium carbonate under the same calcium supplementation effect. It cuts raw material occupancy and formula cost, and improves the cost performance of high-nutrition-density formulas.

3. Expanded Application Boundaries

Breaks the application limitations of traditional calcium sources in transparent beverages, light-colored milk powder, probiotic compound systems and high dietary fiber systems. Enriches product lines, seizes the high-end special diet and health food market, and taps new profit growth points.

4. Full Compliance Risk Avoidance

Fully meets global authoritative standards with qualified heavy metal, microbial and toxicological indicators. No risk of spot inspection or market complaints, strengthening brand professionalism and consumer trust.

V. Target Application Market

- **Infant Formula Food**: Formula milk powder, complementary rice powder, teething biscuits and grain supplementary food (national standard approved high-quality calcium source) for mild calcium supplementation adapting to delicate infant intestines and stomach.
- **Dairy Industry**: Room-temperature milk, fermented yogurt, cheese, modified milk powder and plant-based beverages; odorless, non-precipitating and stable without damaging the original flavor of dairy products.
- **Functional Beverages**: Vitamin fortified drinks, sports nutrition drinks, fruit and vegetable juices and transparent functional drinks; fast dissolution in acidic conditions, stable performance and non-coloring, suitable for industrial production.

- **Health Food**: Calcium tablets, capsules, oral liquids, soft candies, meal replacement powder and compound nutrients; high absorption and non-irritation, suitable for long-term nutritional supplementation.
- **Clinical Special Diet**: Medical nutritional preparations, postoperative rehabilitation formulas, special meals for anemia/osteoporosis and prenatal & lactation nutrition supplements; mild, efficient, safe and compliant to meet the nutritional needs of special groups.
- **Grain & Baking Products**: Nutritional oatmeal, noodles, whole wheat bread, puffed nutritional food and meal replacement bars; high temperature resistance, oxidation resistance and nutrition protection adapting to strict processing technologies.
- **Pet Nutrition Market**: High-end pet food, prescription food for young/pregnant pets and pet nutritional ointment; efficient calcium supplementation, immunity enhancement, odorless property and easy absorption.

Conclusion

With five core advantages of **non-gastric-acid-dependent high absorption, zero gastrointestinal irritation, wide process stability, dietary antagonism resistance and global universal compliance**, Calcium Citrate has become a benchmark of organic calcium nutritional fortifiers. It not only solves the inherent shortcomings of traditional calcium sources such as poor absorption, strong irritation, unstable processing performance and dietary antagonism, but also meets the high-end nutritional demands of the whole life cycle and special physiological stages. It is an irreplaceable high-efficiency, safe, mild and cost-effective calcium fortifying raw material widely applied in the food industry, pharmaceutical health care, special diet and pet nutrition fields.