Industrial Development History of Garlic Extracts

I. Tribute Chapter

Garlic (*Allium sativum L.*), a perennial herbaceous bulb belonging to the genus *Allium* of the Amaryllidaceae family, commonly known as suan or garlic bulb, is a classic sulfur-containing medicinal and edible raw material across five core global sectors: natural antibacterial dietary supplements, cardiovascular care, antibiotic alternatives for feed, antibacterial skincare, and pharmaceutical active ingredients. It is a multi-functional sulfide raw material spanning ten major fields: prehistoric consumption by Central Asian ancestors, herbal medicine in ancient Egypt and Mesopotamia, classical medicine of ancient Greece and Rome, thousand-year inheritance of Chinese Materia Medica, modern microbiological antibacterial verification, natural product chemistry of organosulfur compounds, multi-pathway pharmacology for cardiovascular and cerebrovascular health, stabilized fermented black garlic extracts, antibiotic-free livestock and poultry breeding, and antibacterial skin repair.

Its full developmental timeline covers more than 6,000 years of prehistoric cultivation and medicinal records in ancient texts worldwide, isolation and identification of two core marker compounds—alliin and allicin, discovery of S-allylcysteine (SAC), an aging fermentation product with water solubility, iterative optimization of full-process technologies including low-temperature sealed enzymatic hydrolysis extraction, membrane separation for impurity and irritant removal, directional enrichment of sulfides via macroporous resin, odor elimination and stabilization encapsulation with nanocapsules, and long-term constant-temperature ripening for black garlic. It has formed six core application segments: cardiovascular and cerebrovascular health food, natural food antibacterial preservatives, soothing fermented black garlic beverages, antibacterial repair cosmetics, premix feed as livestock antibiotic alternatives, and pharmaceutical active ingredients.

China has realized domestic mass production of high-purity alliin, stabilized allicin, and deodorized black garlic extracts, and built a globally graded, compliant quality control system covering dietary supplements, food preservation, cosmetics, feed, and pharmaceuticals. Scientific research teams worldwide have dedicated over six millennia to in-depth research on garlic.

We hereby pay tribute to scholars and R&D teams at home and abroad who have achieved full-industry-chain technological breakthroughs, including textual research on prehistoric herbal documents, isolation and qualitative identification of allicin monomers, establishment of quantitative detection systems for alliin, sealed low-temperature enzymatic hydrolysis extraction, removal of pungent impurities via ceramic membranes, sulfide enrichment with macroporous resin, stabilized low-temperature ripening technology for black garlic, verification of molecular antibacterial and vascular-protective mechanisms, construction of domestic solvent-free green extraction production lines, and compliance registration in regulatory jurisdictions across the globe. Out of respect for industry competition and corporate privacy, no enterprise names are listed herein. We also extend our sincere gratitude to all manufacturers that have realized process innovation and full-industrial-chain localization of garlic extracts.

Roll of Honor

1. Milestone Scientists Worldwide (Chronological Order)

- ***Ancestors of the Central Asian Bronze Age (4000–2700 BCE, Tianshan Mountains and Mesopotamia)***

Carbonized garlic bulb relics unearthed from ancient caves in Israel, together with Sumerian cuneiform clay tablets documenting garlic's oral use for fatigue relief and external application for wound anti-inflammation, constitute the earliest surviving empirical evidence of garlic consumption and medicinal use by humans, laying the foundation for folk applications across Eurasia.

- ***Physicians Compiling the Ebers Papyrus, Ancient Egypt (1500 BCE)***

Garlic prescriptions appear more than 20 times in Egypt's core medical text, indicated for headaches, cardiovascular discomfort, insect bites, and intestinal dysentery. Garlic clay figurines unearthed from pharaonic tombs serve as the world's earliest systematic written records of garlic's medicinal value.

- ***Physicians Compiling Vedic Scriptures, Ancient India (2000–800 BCE)***

The Vedas document garlic as a tonic for physical strength, used to treat poor appetite, cough and asthma, rheumatism, and skin ulcers, establishing a complete South Asian system of oral administration and external washing.

- ***Hippocrates (460–370 BCE, Ancient Greece, Father of Medicine)***

He systematically recorded garlic decoctions for vascular unclogging, respiratory infection relief, and indigestion improvement, defining garlic's core positioning as a vascular-protective and broad-spectrum antibacterial herb and laying the origin of Western herbal pharmacology.

- ***Pedanius Dioscorides (70 CE, Ancient Rome)***

In *De Materia Medica*, he distinguished the efficacies of raw garlic, cooked garlic, and garlic oil, clarifying that raw garlic is highly irritating while cooked garlic delivers mild tonic effects, delineating safe dosage limits for internal and external use, and establishing a processing-based medication paradigm adopted across Europe for over a millennium.

- ***Pliny the Elder (23–79 CE, Ancient Rome)***

Naturalis Historia records garlic's military epidemic prevention, insect repellent, and seasoning applications, marking the simultaneous origin of garlic's triple utilization as food, epidemic prevention agent, and medicine.

- ***Zhang Qian and Materia Medica Physicians of the Eastern Han Dynasty (130 BCE – 200 CE, China)***

Garlic was introduced to the Central Plains from Central Asia via the Silk Road. *Records of Famous Physicians* documents garlic as a medicinal herb with effects of warming the middle jiao, detoxification, and dysentery relief, launching a two-thousand-year lineage of garlic applications in Chinese Materia Medica.

- ***Li Shizhen (1596, Ming Dynasty, China)***

Compendium of Materia Medica systematically summarizes compound formulas of garlic for oral treatment of cholera, dysentery, cough and asthma, as well as external use for detumescence, nasal congestion relief, and guiding fire downward. It standardized traditional domestic processing techniques including harvesting, vinegar soaking, and steaming/boiling to reduce toxicity.

- ***Louis Pasteur (1858, French Microbiologist)***

For the first time globally, laboratory experiments proved garlic juice broadly inhibits bacterial reproduction, scientifically validating its folk antibacterial efficacy and inaugurating the modern pharmacological research era of garlic.

- ***Chester J. Cavallito & John Hays Bailey (1944, Winthrop Laboratories, USA)***

Globally first isolated, purified, and named allicin from enzymatic hydrolysate of fresh garlic, analyzed its antibacterial activity, and identified allicin as garlic's core efficacy marker compound.

- ***R&D Team of Sterling Drug (1950, USA)***

Published patents for the chemical synthesis of allicin, analyzed the molecular structure of thiosulfinates, clarified the activity of allicin decomposition products diallyl disulfide and diallyl trisulfide, and developed the first-generation detection method for organosulfur compounds.

- ***Black Garlic R&D Group, Japan (1980–1990)***

Developed room-temperature long-duration temperature-controlled fermentation technology for black garlic, isolated and identified water-soluble stable active substance S-allylcysteine (SAC), resolved the pain points of fresh garlic's irritation and allicin's easy decomposition, and created a new category of fermented stabilized garlic extracts.

- ***Herbal Expert Group of ESCOP, Germany (1996)***

Released a monograph on garlic herbal medicine, specifying that standardized garlic extracts are indicated for hyperlipidemia, atherosclerosis, and upper respiratory tract infection prevention, and unified European quality control standards for the minimum alliin content in raw materials.

- ***Domestic Alliin Purification Research Group (2014, China)***

Independently prepared national standard reference substances for alliin, filling the domestic gap in testing reference standards, realizing simultaneous quantitative detection of dual indicators (alliin/allicin) via HPLC, and aligning with the quality control systems of the United States Pharmacopeia (USP) and European Pharmacopoeia.

- ***Domestic R&D Team for Low-Temperature Enzymatic Hydrolysis Extraction (2000–2015, China)***

Independently developed integrated mass production technologies including sealed low-temperature enzymatic hydrolysis, removal of pungent macromolecular impurities via ceramic membranes, directional enrichment of organosulfur compounds with macroporous resin, and vacuum low-temperature concentration. The technologies addressed two major industry pain points: rapid degradation of allicin under traditional high-temperature extraction and excessive residual irritant substances.

- ***Supercritical CO_2 Extraction Technology Research Group (2008–2018, China)***

Realized industrial solvent-free low-temperature extraction of garlic oil, drastically reducing organic solvent residues and supporting the production of pharmaceutical-grade high-purity allicin active ingredients.

- ***Herbal Medicinal Products Committee (HMPC) Expert Group, European Medicines Agency (2007)***

Released a garlic herbal monograph, unifying global basic quality control specifications covering garlic ripeness at harvest, heavy metals, solvent residues, and alliin content, and defining safe oral dosage ranges.

- ***Multinational Clinical Evidence Teams for Cardiovascular Health (2000–2022, Europe, America, China, Japan)***

Completed multi-center randomized double-blind human clinical trials, confirming standardized garlic extracts lower blood pressure, regulate blood lipids, and inhibit platelet aggregation, and perfecting the human clinical evidence chain for cardiovascular protection.

- ***New Food Raw Material Review Expert Group, National Health Commission of China (2010–2024, China)***

Completed full toxicology, cumulative toxicity, and population safety assessments for garlic extracts and black garlic extracts, included them in catalogs of food raw materials and health food raw materials, clarified daily intake limits and unsuitable populations, and improved domestic regulatory systems.

- ***USP-NF Editorial Team (2010, USA)***

Added a monograph for dried garlic extracts, stipulated the statutory HPLC minimum alliin content standard, and incorporated garlic extracts into the global general quality control system for dietary supplements.

- ***Domestic R&D Team for Feed Antibiotic Alternatives (2015–2026, China)***

Developed low-irritation deodorized garlic extract premixes, completed full animal trials for intestinal antibacterial effects and growth promotion in livestock and poultry, realized substitution of antibiotics, and matched national standards for safety limits of feed raw materials.

- ***Domestic Natural Product Safety Evaluation Research Institute Team (2026, China)***

Formulated full safety limit indicators for garlic extracts across four categories of raw materials: food, cosmetics, feed, and pharmaceuticals, and established supporting national standard methods for simultaneous detection of organosulfur compounds, heavy metals, microorganisms, and solvent residues.

2. Overall Contributions of Core Scientific Research Teams

- ***Eurasian Prehistoric & Classical Medical Schools:***

  Established a 6,000-year folk application system of fresh garlic mashing, vinegar soaking, steaming and boiling for oral and external use, designated authentic garlic producing regions in Central Asia, North China, and Southern Europe, and preserved traditional processed compound formulas for toxicity reduction.

- ***Chinese Materia Medica Textual Research Teams:***

  Improved the TCM system of garlic's nature, flavor, meridian tropism, toxicity reduction via processing, and syndrome differentiation-based applications, forming traditional dietary and external use regimens suitable for East Asian populations.

- ***Modern Microbiological Verification Schools:***

  Pasteur's team provided the first scientific proof of garlic's natural antibacterial activity, bridging traditional empirical knowledge and modern microbiology.

- ***European and American Natural Medicinal Chemistry Research Teams:***

  Completed isolation and qualitative identification of alliin, allicin, SAC, and diallyl sulfides, built multi-indicator simultaneous quantitative detection systems via HPLC-UV/MS, and developed basic purification technologies including enzymatic hydrolysis extraction, membrane separation impurity removal, and resin enrichment.

- ***Cardiovascular and Immune Pharmacology R&D Teams:***

  Verified the antibacterial, anti-inflammatory, lipid and blood pressure regulating, and immunity-enhancing pathways of organosulfur compounds step-by-step through in vitro tests, animal experiments, and multi-center human clinical trials, pioneering the core oral dietary segment for cardiovascular and cerebrovascular health.

- ***Black Garlic Fermentation Stabilization R&D Teams:***

  Invented long-duration temperature-controlled ripening technology to convert unstable allicin into water-soluble stable SAC, eliminate pungent irritation, and expand the mild daily nutrition segment.

- ***Global Compliance and Pharmacopoeia Regulatory Teams:***

  Promoted garlic's inclusion in European and American pharmacopoeias, USP dietary supplement catalogs, German Commission E herbal lists, China's health food raw material catalogs, and feed additive catalogs, smoothing global import and export circulation channels.

- ***Domestic Garlic Resource Domestication Research Groups:***

  Relying on large-scale planting bases in Jinxiang (Shandong) and Zhongmu (Henan), selected superior cultivated varieties with high alliin content and low irritation, and built a full localized standardized planting chain.

- ***Domestic R&D Teams for Standardized Green Low-Temperature Extraction:***

  Independently developed a full set of mass production technologies including sealed low-temperature enzymatic hydrolysis, ceramic membrane removal of pungent impurities, macroporous resin enrichment of organosulfur compounds, supercritical solvent-free extraction, vacuum low-temperature concentration, and nanocapsule odor elimination and stabilization, achieving independent control over high-end alliin and stabilized allicin raw materials.

- ***Industrial R&D Teams for Six Major Segments:***

  Developed graded customized raw materials targeting cardiovascular health food, natural food antibacterial preservatives, soothing fermented black garlic beverages, antibacterial repair cosmetics, livestock antibiotic-alternative feed, and pharmaceutical active ingredients, expanding diversified industrial application scenarios for garlic extracts.

II. R&D History

1. Period of Traditional Folk Native Application and Basic Exploration (4000 BCE – 1943)

1.1 4000 BCE – 1857: Stage of Direct Mashing and Crude Processing of Fresh Garlic

In ancient Central Asia, Egypt, India, Greece, Rome, and China, only ripe fresh garlic was harvested, processed into mashed garlic for external application or garlic juice for oral intake, or soaked in vinegar, steamed, or boiled to reduce toxicity before consumption. Processing methods relied on manual mashing, open-pot boiling, and simple

filtration via natural sedimentation, without separation purification or activity stabilization technologies.

Allicin decomposed rapidly at room temperature, high temperature, or in acidic environments and could not be stored long-term; polysaccharides, proteins, and pungent macromolecular impurities could not be removed. Only homemade mashed garlic, garlic juice, and vinegar-preserved garlic circulated among the public; no standardized extract raw materials were traded, and there was no concept of quantitative quality control for active substances. Physicians of successive dynasties accumulated basic safety cognition: raw garlic is irritating, cooked garlic mild, and vinegar soaking reduces toxicity.

1.2 1858 – 1943: Confirmation of Antibacterial Effects, Without Monomer Isolation or Standardized Extraction

In 1858, Pasteur proved garlic juice inhibits pathogenic bacterial growth via microbiological experiments, launching modern scientific research on garlic. However, core active monomers remained unisolated for nearly a century, with research limited to observing antibacterial effects of crude juice. Traditional crude products produced via open-pot high-temperature boiling or open distillation suffered three critical drawbacks:

① Allicin, the core functional compound, decomposes rapidly under heat, drastically attenuating antibacterial and vascular-protective effects;

② Macromolecular pungent impurities cannot be eliminated, causing gastrointestinal irritation upon oral administration and skin burns for external use;

③ Extracts contain abundant polysaccharide and protein impurities, prone to turbidity, fermentation, and microbial proliferation, failing to meet industrial standards for food, cosmetics, and pharmaceuticals.

1.3 R&D Objectives of This Stage

Develop fully sealed controllable low-temperature enzymatic hydrolysis, directional removal of pungent macromolecular impurities via ceramic membranes, directional enrichment of organosulfur compounds with special macroporous resin, supercritical solvent-free extraction, and nanocapsule odor elimination and stabilization encapsulation technologies. Produce standardized garlic extracts with low irritation, long shelf life, and high alliin/stabilized allicin content to realize impurity removal while fully retaining heat-sensitive active ingredients. Develop long-duration temperature-controlled fermentation technology for black garlic to convert unstable allicin into water-soluble stable SAC.

1.4 Core Conclusions

Garlic's core functional substance system consists of organosulfur complexes: alliin (precursor marker), allicin (enzymatic active substance), S-allylcysteine (fermentation stabilization marker), and characteristic components diallyl disulfide/trisulfide, which deliver broad-spectrum antibacterial, anti-inflammatory, lipid and blood pressure regulating, and antioxidant effects.

Raw garlic contains highly irritating volatile sulfides; allicin degrades rapidly under high temperature and acidic conditions, and crude products face pain points including gastrointestinal irritation, activity loss, and deterioration during storage. Low-temperature sealed graded purification, fermentation stabilization, and deodorization encapsulation of garlic extracts have become core global R&D directions for the industry.

2. Period of Allicin Monomer Isolation and Maturation of First-Generation Extraction Processes (1944–1999)

2.1 1944 – 1950: Isolation and Qualitative Identification of Allicin, Commercialization of Synthetic Technology

In 1944, Cavallito's team isolated and named allicin and analyzed its antibacterial activity. Artificial synthesis patents for allicin were published in 1950, paired with the launch of first-generation chromatographic detection methods. Laboratories in Europe and America adopted small-scale steam distillation to extract garlic oil for limited supply to pharmaceutical antibacterial preparations. Meanwhile, China only produced crude garlic powder and flakes for folk use, with no standardized purification capacity; high-purity allicin active ingredients relied entirely on imports.

2.2 1951 – 1989: Birth of Solvent Extraction and Black Garlic Fermentation Technology

Ethanol solvent extraction replaced traditional steam distillation, boosting extraction efficiency by over 40%. Japan developed temperature-controlled fermentation technology for black garlic and discovered stable water-soluble SAC, resolving fresh garlic's irritation and allicin instability and creating a new nutrition category of fermented black garlic extracts. Supporting basic acute toxicity and skin irritation safety tests were completed to define safe addition ranges for oral and external use. Germany's Commission E incorporated garlic herbal standards, and Europe's quality control system took initial shape.

2.3 1990 – 1999: Industrialization of Resin Enrichment and Enzymatic Hydrolysis Processes

Macroporous adsorption resin realized directional enrichment of organosulfur fractions, greatly elevating alliin content in lyophilized powder. Controllable sealed low-

temperature enzymatic hydrolysis technology was commercialized to precisely regulate the conversion efficiency of alliinase and maximize allicin retention. In 1996, ESCOP released a garlic herbal monograph unifying grading standards for European health food raw materials. Large-scale garlic planting bases were built in Shandong and Henan, China, launching R&D on small pilot extraction production lines.

3. Period of Global Clinical Evidence and Multi-Country Regulatory Standardization (2000–2014)

3.1 2000 – 2010: Full Rollout of Multi-Center Human Efficacy Clinical Trials

Summary of randomized controlled trials worldwide confirms continuous oral administration of standardized alliin garlic extracts slightly lowers systolic blood pressure in hypertensive populations, reduces total cholesterol and low-density lipoprotein, and inhibits platelet aggregation. Fermented black garlic SAC extracts deliver prominent antioxidant and immune-regulating effects without gastrointestinal irritation. Supporting in vitro and animal tests were completed for natural food preservation, antibacterial skin repair, and intestinal antibiotic substitution in livestock.

Global market demand for natural antibacterial and cardiovascular nutrition products maintained steady growth, making garlic extracts an essential natural functional raw material.

3.2 2011 – 2014: Formation of Global Four-Tier Raw Material Regulatory Standard System

A unified four-tier classification system for garlic raw materials was established globally:

① Crude processed garlic powder/flakes (total alliin: 0.1%–0.5%, used for condiments and low-end feed);

② Low-temperature enzymatic hydrolysis concentrated juice (total alliin: 0.5%–2%, used for common beverages and general preservative additives);

③ Resin-enriched lyophilized powder (total alliin: 2%–10%, used for health food, mild nutrition for children, and pet care);

④ High-purity alliin/allicin active pharmaceutical ingredients (total alliin ≥10%, used for pharmaceuticals, high-end medical aesthetics, and premium dietary supplements).

Registration filings were completed for FDA dietary supplements, European EDQM herbal standards, German Commission E herbal catalog, and Japanese food additives.

Domestic supporting standards were simultaneously improved: access standards for food preservatives under GB 2760, the Catalog of Cosmetic Raw Materials in Use, and safety limits for feed additives were fully updated, covering detailed testing rules for four categories of raw materials (food, cosmetics, feed, pharmaceuticals) and forming a full-segment standardized management system. Domestic R&D on national standard reference substances for alliin was initiated to fill domestic testing gaps.

4. Period of Domestic Independent Process Substitution and Full Industrial Chain Maturation (2015–2026)

4.1 2015 – 2022: Comprehensive Breakthrough of Domestic Green Extraction Technology, Local Production Lines Matching Imported European and American Standards

In 2014, China independently prepared national standard reference substances for alliin, localizing the HPLC dual-indicator detection system. Domestic enterprises built complete production lines for sealed controllable low-temperature enzymatic hydrolysis, addressing four major deficiencies of imported products: high-temperature degradation of allicin, incomplete removal of pungent impurities, strong extract irritation, and easy oxidation of powder during storage.

A full set of supporting technologies was commercialized: supercritical CO_2 solvent-free extraction, ceramic membrane impurity removal, macroporous resin enrichment, and constant-temperature black garlic fermentation. Product indicators including alliin content, solvent residues, microorganisms, and storage stability fully matched imported European and American raw materials, while overall production costs decreased significantly. Domestic products fully replaced imported standard extracts for mid-to-low-end applications, and domestic high-purity allicin APIs gradually broke import monopolies.

China built over 12 million mu of standardized contiguous garlic planting bases, forming a fully closed-loop industrial chain:

Harvest ripe garlic under light-proof temperature control → sealed low-temperature transportation within 4 hours → peeling, clove separation, cleaning and grading → controllable low-temperature enzymatic hydrolysis / long-duration temperature-controlled fermentation → removal of pungent macromolecular impurities via ceramic membranes → directional enrichment of organosulfur compounds with macroporous resin → supercritical extraction / vacuum low-temperature concentration / lyophilization → nanocapsule odor elimination and stabilization encapsulation → light-proof low-temperature sterile warehousing.

4.2 2023 – 2026: Comprehensive Iteration and Upgrade of Customized Products for Six Segments

The industry formed gradient customized products: food-grade garlic concentrated juice, low-irritation black garlic fermentation broth, high-alliin lyophilized powder for health food, high-purity pharmaceutical-grade alliin APIs, mild antibacterial skincare extracts, and livestock antibiotic-alternative premixes.

Low-temperature enzymatic hydrolysis and supercritical solvent-free green extraction were widely adopted across the industry, drastically cutting organic solvent consumption and three-waste emissions. China unified supporting national standard HPLC simultaneous quantitative detection methods for alliin + allicin. Nanocyclodextrin encapsulation technology resolved organosulfur volatility and gastrointestinal irritation pain points, adapting to full dosage forms including oral liquids, compressed candies, gummy candies, functional beverages, antibacterial facial masks, wash care products, livestock feed pellets, and oral pharmaceuticals. Driven by the global antibiotic ban policy for feed, the market for deodorized garlic extracts as antibiotic alternatives expanded rapidly.

III. Commercialization Development History

1. Stage of Crude Fresh Garlic Processing and Microscale Laboratory Extraction (4000 BCE – 1943)

Indigenous peoples across Eurasia only produced homemade dietary and external preparations via mashing, vinegar soaking, or boiling fresh garlic for personal use. Laboratories in Europe and America extracted trace amounts of allicin solely for pharmacological and microbiological research, with no standardized commercial extract raw materials available. China only processed crude garlic powder and flakes, lacking industrial purification factories; no compliant standardized garlic extract commodities circulated in the market.

Industrial characteristics: Absence of technologies including sealed low-temperature enzymatic hydrolysis, membrane-based pungent impurity removal, resin organosulfur enrichment, fermentation stabilization, and nanocapsule deodorization; no unified global quality control grading standards; the industrial sector for standardized extracts was entirely non-existent.

2. Stage of Early European and American Industrialization, Full Import Dependence on Domestic High-End Raw Materials (1944–1999)

2.1 1944 – 1989: Small-Scale Mass Production of Standardized Raw Materials in Europe and America

Steam distillation and ethanol extraction processes matured, and Europe and America launched garlic oil antibacterial pharmaceuticals and garlic dietary supplement capsules. Global annual consumption of standardized garlic extracts reached approximately 2,100 tons in 1990, with markets concentrated in European and American pharmacies and natural dietary supplement brands. China only exported small volumes of crude garlic products, lacking high-purity purification capacity; all standardized extracts required for pharmaceuticals and high-end health food relied on imports.

2.2 1990 – 1999: Low-End Domestic Industry, High Price of Imported High-Purity Raw Materials

Enterprises from Europe, America, and Japan monopolized core purification technologies including low-temperature enzymatic hydrolysis, resin enrichment, and black garlic fermentation. Imported high-alliin lyophilized powder and pharmaceutical-grade allicin carried high unit prices, supplied exclusively to overseas high-end dietary supplements, hospital antibacterial skincare, and pharmaceutical APIs. China held no compliant qualifications for high-purity food/pharmaceutical-grade raw materials and only exported low-end garlic powder and flakes, which failed to meet health food and pharmaceutical standards due to excessive pungent impurities and solvent residues.

Industrial characteristics: Overseas enterprises held full core technologies for active ingredient purification, irritation reduction, and stabilization; China possessed abundant

large-scale garlic planting resources but lacked supporting systems for industrial intensive extraction and multi-indicator detection, and domestic market awareness of graded standardized garlic extracts remained extremely low.

3. Stage of Domestic Production Capacity Maturation and Rapid Expansion of Six Application Segments (2000–2022)

Global market demand simultaneously surged for natural antibiotic-alternative feed, cardiovascular nutrition, natural food preservation, mild antibacterial skincare, fermented black garlic beverages, and pharmaceutical APIs, making garlic extracts an indispensable multi-functional natural functional raw material. Global annual consumption of all categories of raw materials exceeded 16,200 tons in 2022.

China fully commercialized six application segments: cardiovascular regulatory health food, natural food antibacterial preservatives, soothing functional black garlic beverages, antibacterial repair cosmetics, antibiotic-free livestock feed, and pharmaceutical antibacterial APIs. In 2022, China realized stable large-scale mass production of domestic standardized concentrated juice, medium/low-alliin lyophilized powder, and black garlic fermented extracts, breaking long-term European and American monopolies over basic raw material technologies. Domestic annual market consumption reached 5,600 tons, with annual exports of standardized garlic extracts hitting 7,200 tons.

A complete localized full industrial chain supporting system took shape, providing integrated technical services covering raw material testing, terminal formula compounding, and dosage form development, fully covering all application scenarios of food, cosmetics, health food, feed, and pharmaceuticals.

4. Stage of Highly Mature Industry and Large-Scale Global Exports of Domestic Raw Materials (2023–2026)

4.1 Clear Product Stratification, Precise Coverage of All Application Scenarios

The four-tier raw material gradient features clear positioning and differentiated competition: crude garlic powder/flakes exclusively for condiments and low-end livestock feed; low-temperature enzymatic hydrolysis concentrated juice for beverages and natural food preservation; resin-enriched lyophilized powder for cardiovascular health food, black garlic nutrition, and pet intestinal care; high-purity alliin/allicin APIs for pharmaceuticals and high-end medical aesthetic repair, achieving full coverage of high and low-end markets.

4.2 Mass Export of Domestic Raw Materials, Continuous Growth of Global Market Share

Domestic garlic extracts match top-tier European and American brands in all indicators including alliin stability, low-irritation impurity removal, and solvent residues.

Leveraging the world's largest domestic large-scale garlic planting supply chain, customized low-temperature enzymatic hydrolysis purification, fermentation stabilization, nanotechnology deodorization processes, and cost advantages, domestic extracts are exported in bulk to the EU, North America, Southeast Asia, Japan, South Korea, and Australia, continuously eroding the market share of traditional overseas raw material manufacturers. Fermented black garlic extracts occupy mainstream overseas functional beverage markets with their unique mild, non-irritating advantages.

4.3 Formation of Standardized, Healthy Industrial Competition Landscape

Industry supervision centers on USP-NF, European ESCOP herbal monographs, German Commission E standards, China's Catalog of Health Food Raw Materials, Catalog of Feed Additive Varieties, and Catalog of Cosmetic Raw Materials in Use, setting access thresholds for safety limits of alliin, solvent residues, and heavy metals for food/pharmaceutical-grade raw materials. Imported high-purity allicin APIs are only supplied in small volumes to high-end specialty pharmaceutical brands, while domestic graded standardized raw materials dominate the domestic mass market and emerging overseas markets. Industry competition has shifted from early price wars over crude garlic powder to comprehensive strength competition covering alliin purity, customized pungency reduction, storage stability, and multi-country global compliance support.

4.4 Medium and Long-Term Industrial Development Trends (Post-2026)

- ***Full-Process Sealed Green Low-Temperature Production to Be Fully Popularized***

Large-scale promotion of controllable low-temperature enzymatic hydrolysis, supercritical CO_2 solvent-free extraction, low-temperature ceramic membrane removal of pungent impurities, and bio-enzymatic polysaccharide/protein removal technologies. Full-process light-proof temperature control eliminates degradation of heat-sensitive organosulfur compounds. Garlic peel and pomace by-products are fermented for resource utilization into composite antibacterial feed raw materials, realizing full-plant circular green garlic production.

- ***Precise Customized Graded Special Raw Materials for Segmented Sectors***

Develop special graded raw materials with differentiated alliin content, irritation levels, water solubility, and acid/alkali resistance targeting six segments: cardiovascular health food, oral black garlic beverages, clean-label natural preservatives, antibacterial cosmetics for sensitive skin, livestock antibiotic-alternative feed, and pharmaceutical antibacterial APIs.

- ***Development of Integrated Pre-Compound Raw Materials***

Formulate pre-compounded raw materials for cardiovascular and intestinal health by matching garlic with red yeast rice, ginkgo biloba, grape seed, and probiotics, reducing secondary compounding procedures for terminal manufacturers and providing one-stop finished formula solutions.

- ***Integrated Global Multi-Regional Compliance Layout***

Complete simultaneous registration and certification for China's health food raw materials, EU herbal raw materials, U.S. dietary supplements, Japanese food additives, and Canadian natural health products, unifying testing criteria and limit standards across jurisdictions to achieve barrier-free cross-border circulation of garlic raw materials worldwide.

- ***Continuous Iteration of High-Stability Delivery Technologies***

Nanoliposome and cyclodextrin composite microcapsule wrapping technologies improve oral bioavailability and transdermal absorption rate of alliin. Develop high-end dosage forms including sterile single-dose oral liquids, sustained-release chewable tablets, controlled-release gummy candies, medical antibacterial repair essences, and aquaculture antibiotic-alternative micro-pellets. Advance garlic cell suspension culture to enrich alliin, breaking supply restrictions of field planting seasons and land resources. Iterate low-irritation odorless alliin extracts to expand segmented markets for children and gastrointestinal-sensitive populations.

Conclusion

The garlic extract industry originates from over 6,000 years of consumption and medicinal practices of prehistoric Central Asian ancestors, passing through classical medicine of ancient Egypt, Greece, and Rome, as well as two thousand years of inheritance in Chinese Materia Medica. It has evolved into a mainstream global standardized organosulfur functional raw material sector covering six major fields: cardiovascular regulatory health food, natural food antibacterial preservatives, soothing fermented black garlic beverages, antibacterial repair cosmetics, antibiotic-free livestock feed, and pharmaceutical antibacterial active ingredients.

It has completed a full developmental cycle spanning textual research on prehistoric herbal documents, isolation and identification of dual characteristic markers (alliin/allicin), multi-center human cardiovascular clinical evidence verification, sealed controllable low-temperature enzymatic hydrolysis extraction, ceramic membrane removal of pungent impurities, directional enrichment of organosulfur compounds via macroporous resin, constant-temperature black garlic fermentation stabilization, nanocapsule odor elimination encapsulation, and independent technological catch-up by domestic manufacturers. The industry has realized full-chain upgrading from fresh raw garlic and crude garlic powder/flakes to globally graded high-end standardized organosulfur extract raw materials.

Compared with crude garlic products processed via traditional open-pot high-temperature boiling without pungent impurity removal, standardized low-temperature graded garlic extracts adopt five core technologies: sealed controllable low-temperature enzymatic hydrolysis, ceramic membrane removal of macromolecular irritant impurities, macroporous resin organosulfur enrichment, supercritical solvent-free extraction, and nanocyclodextrin odor elimination stabilization. They feature core competitive strengths including full retention of active alliin, drastically reduced gastrointestinal irritation, long-term stability against light and high temperature, ultra-low organic solvent residues, compatibility with full dosage forms for food/cosmetics/feed/pharmaceuticals, and multi-country global compliance filings. They perfectly align with long-term global market development trends including natural antibiotic-free breeding, chronic cardiovascular disease nutrition, clean-label natural preservation, mild skincare, and non-irritating daily dietary therapy.

With the continuous commercialization of solvent-free green extraction, customized graded raw materials for segmented sectors, nanotechnology stabilization delivery, plant cell suspension culture, and low-irritation odorless alliin new technologies, garlic extracts will maintain a long-term core position as primary raw materials for natural antibacterial applications, cardiovascular care, and feed antibiotic substitution, becoming an indispensable multi-functional mainstream Allium medicinal and edible raw material for the health food, cosmetics, livestock breeding, and pharmaceutical industries.