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Review Article

A Review of Alum and Kaolin Particles in Pharmacognosy: Traditional Uses, Physicochemical Characteristics, and Therapeutic Applications

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ABSTRACT

Naturally occurring mineral-based substances have held a significant place in both traditional and modern medicine due to their therapeutic, adsorptive, and protective properties. Among these, kaolin (hydrated aluminum silicate) and alum (a double sulfate salt of aluminum and potassium or ammonium) are widely used inorganic materials with a long history of medicinal application. Kaolin acts primarily as an adsorbent, while alum is valued for its astringent, antiseptic, and hemostatic actions. This review provides a comprehensive discussion of the origin, physicochemical properties, pharmacognostic significance, historical and contemporary therapeutic uses, safety considerations, and pharmaceutical applications of kaolin and alum particles. Their roles as excipients, detoxifying agents, topical remedies, and modern adjuvants are examined, highlighting their importance in both conventional and traditional healthcare systems. The review further explores emerging nanotechnological applications and emphasizes the need for rigorous standardization and scientific validation to fully harness their therapeutic potential.

INTRODUCTION

Pharmacognosy, the science of naturally derived substances used in medicine, encompasses materials from plant, animal, microbial, and mineral origins. Among these, mineral-based drugs occupy a distinct niche due to their exceptional physicochemical stability, broad therapeutic versatility, and enduring presence in traditional medical systems such as Ayurveda, Unani, Siddha, and folk medicine. Kaolin and alum are prime examples of minerals that have been employed for centuries as remedial and protective agents. Despite their extensive historical use, these materials have received considerably less attention in contemporary pharmacognostic research compared to herbal drugs [1–3].

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Kaolin, commonly known as China clay, is a naturally occurring hydrated aluminum silicate (idealized formula $Al_2Si_2O_5(OH)_4$) formed by the hydrothermal weathering of feldspar-rich rocks. It is characterized by a fine particle size, large specific surface area, chemical inertness, and notable adsorptive capacity. Traditionally, kaolin has been used as an oral antidiarrheal agent because it adsorbs bacterial toxins, enteropathogens, and excess fluid within the gastrointestinal tract. In modern pharmacognosy, kaolin is classified as an inorganic adsorbent and pharmaceutical excipient, finding application in oral suspensions, topical dusting powders, and dermatological formulations. Its low cost, safety, and effectiveness have ensured its continued relevance [4–6].

Alum, chemically potassium aluminum sulfate dodecahydrate ($KAl(SO_4)_2 \cdot 12H_2O$) or its ammonium analog, is a mineral salt with potent astringent, antiseptic, and hemostatic properties. In traditional medicine, it is applied externally to arrest bleeding from minor cuts, as a gargle for sore throat and oral ulcers, and as a topical agent for excessive sweating and skin infections. In contemporary medicine, alum has achieved a new dimension of importance through its use as an immunological adjuvant in vaccines (in the form of aluminum hydroxide or aluminum phosphate gels) and as a flocculant in water purification. Its multifaceted functional utility underscores the pharmacognostic value of this seemingly simple inorganic compound [7–9].

The scope of kaolin and alum extends well beyond their classical therapeutic roles. Both serve as pharmaceutical excipients that contribute to the stability, controlled release, and organoleptic properties of formulations. Recent advances in materials science and nanotechnology have further broadened their potential: nano-sized kaolin and alum particles are being investigated for targeted drug delivery, enhanced antimicrobial activity, and improved bioavailability of active pharmaceutical ingredients [10,11].

Nevertheless, significant challenges impede the broader pharmaceutical acceptance of these minerals. Variability in geological source, inadequate purification, lack of particle size uniformity, and the possible presence of heavy metal contaminants necessitate rigorous quality control. The absence of harmonized regulatory monographs for many mineral excipients further complicates standardization. This review aims to provide a comprehensive and critical overview of kaolin and alum in pharmacognosy, covering their origin, physicochemical characteristics, traditional and modern therapeutic uses, pharmaceutical applications, safety profiles, and future prospects. By bridging ethnopharmacological knowledge with contemporary scientific evidence, this paper highlights the potential of these mineral agents as valuable, yet underexploited, components of modern therapeutics.

Kaolin in Pharmacognosy

Origin and Composition

Kaolin is a secondary mineral formed by the chemical weathering of aluminosilicate-rich parent rocks, particularly feldspar, under acidic, low-temperature hydrothermal conditions. The name derives from the Chinese locality “Gaoling,” where it was first mined for porcelain. Major deposits are found in India, China, Brazil, the United States, and the United Kingdom. The mineral is composed predominantly of the clay mineral kaolinite, a 1:1 dioctahedral phyllosilicate with the theoretical formula $Al_2Si_2O_5(OH)_4$. Commercial pharmaceutical-grade kaolin contains at least 95% kaolinite, with minor amounts of quartz, illite, and anatase [4,12].

Physicochemical Properties

- Appearance: Fine, soft, white or off-white powder with a characteristic earthy feel.
- Organoleptic: Odorless and tasteless.
- Solubility: Practically insoluble in water, organic solvents, and dilute acids.
- Surface characteristics: High specific surface area (typically 7–30 m^2/g) and a cation-exchange capacity of 3–15 meq/100 g, conferring substantial adsorptive power.
- Stability: Chemically inert under normal conditions; non-toxic and non-irritating.

These properties are central to kaolin's role as an adsorbent and protective coating agent.

Pharmacognostic Importance

In pharmacognosy, kaolin is classified as a mineral adsorbent and a mechanical protectant. Its adsorptive action is based on the presence of negatively charged siloxane surfaces and electropositive edge sites that can bind cations, polar molecules, and bacterial toxins via electrostatic interactions, hydrogen bonding, and van der Waals forces. When administered orally, kaolin forms a thin, adherent layer over the gastrointestinal mucosa, shielding it from irritants and reducing fluid loss [5,13].

Traditional and Therapeutic Uses

- **Antidiarrheal:** Kaolin is a classic remedy for acute, nonspecific diarrhea. It adsorbs enterotoxins produced by *Escherichia coli* and *Vibrio cholerae*, as well as excess water, thus normalizing stool consistency. It is frequently combined with pectin to enhance its demulcent effect.
- **Detoxification:** Historically, kaolin has been ingested to bind ingested poisons and heavy metals, although modern activated charcoal has largely superseded it for this purpose.
- **Topical applications:** Kaolin cataplasms (poultices) are applied to inflamed skin, insect bites, and minor burns to absorb exudates, reduce irritation, and promote cooling.
- **Gastrointestinal protectant:** Used as a bulking agent and mucosal protectant in certain functional bowel disorders.

Pharmaceutical Applications

- **Excipient:** Kaolin is widely used in tablet and capsule formulations as a diluent, adsorbent, and disintegrant. It also serves as a suspending agent for insoluble drugs in liquid orals.
- **Topical preparations:** Incorporated into dusting powders, face masks, and antiseptic talcs for its absorbent, oil-adsorbing, and skin-soothing properties.
- **Cosmetic and dermatological products:** Due to its mildness and absorbency, kaolin is a common ingredient in cosmetic clays and dermocosmetic formulations.

Safety Profile and Considerations

Kaolin is generally regarded as safe (GRAS) when used in purified form and within recommended limits. Orally, it is not absorbed systemically to any appreciable extent. However, chronic ingestion of large doses may lead to constipation, intestinal obstruction, and potential interference with the absorption of concurrently administered drugs (e.g., digoxin, tetracyclines, lincomycin). Inhalation of kaolin dust over prolonged periods can cause pneumoconiosis (kaolinosis) and should be strictly avoided during handling. Regulatory

compliance for heavy metal content (lead, arsenic, cadmium) is essential to ensure safety [14].

Alum in Pharmacognosy

Origin and Chemical Nature

Alum broadly refers to hydrated double sulfate salts with the general formula $M^{+}M^{3+}(SO_4)_2 \cdot 12H_2O$. The most common medicinal form is potash alum ($KAl(SO_4)_2 \cdot 12H_2O$), a colorless crystalline solid. Ammonium alum ($NH_4Al(SO_4)_2 \cdot 12H_2O$) is also used. Alum occurs naturally as the mineral kalinite in volcanic fumaroles and evaporite deposits, but it is predominantly manufactured synthetically from bauxite and sulfuric acid. Medicinal use of alum dates back to ancient Egypt, Greece, and India [7,15].

Physicochemical Properties

- Appearance: Colorless, transparent octahedral crystals or white crystalline powder.
- Solubility: Freely soluble in water (approximately 14 g/100 mL at 20°C); insoluble in ethanol.
- Taste: Strongly astringent and sweetish afterward.
- pH: Aqueous solutions are acidic (pH ~3–4) due to the hydrolysis of the Al^{3+} ion, which precipitates proteins and denatures microbial enzymes.
- Stability: Stable in air but effloresces slightly in dry conditions.

Pharmacognostic Significance

Alum is classified as a mineral astringent and antiseptic in pharmacognosy. Its astringency results from the precipitation of proteins on the surface of tissues, forming a protective coagulum that reduces exudation and bleeding. The acidic, hypertonic environment it creates exerts a bacteriostatic effect against a range of Gram-positive and Gram-negative organisms. These dual actions make alum exceptionally useful in wound management, oral care, and dermatology [8,16].

Traditional and Therapeutic Uses

- **Hemostatic:** Crystals or concentrated solutions of alum are applied directly to minor cuts, shaving nicks, and dental extraction sites to rapidly arrest bleeding.
- **Oral and throat infections:** Diluted alum solution (1–2%) is used as a gargle for sore throat, pharyngitis, and aphthous ulcers due to its antimicrobial and astringent effects.
- **Hyperhidrosis and skin infections:** Alum is a traditional remedy for excessive sweating; it is applied as a powder or in solution to the axillae and feet to reduce perspiration and odor.
- **Hemorrhoids and fissures:** Alum compresses are used to shrink hemorrhoidal tissue and reduce inflammation.
- **Dental hygiene:** Alum powder, alone or mixed with herbal ingredients, is employed as a tooth cleanser and gum astringent.

Pharmaceutical and Industrial Applications

- **Topical antiseptic formulations:** Alum is incorporated into styptic pencils, aftershave lotions, and antiseptic powders.
- **Vaccine adjuvant:** Aluminum salts (aluminum hydroxide, aluminum phosphate, and potassium aluminum sulfate) are the most widely used adjuvants in licensed human

vaccines. They enhance the immunogenicity of antigens by forming a depot at the injection site and by activating the NLRP3 inflammasome [9].

- **Water purification:** Alum acts as a flocculant, clarifying turbid water by aggregating suspended particles.
- **Preservative and stabilizing agent:** Historically used to harden gelatin capsules and to preserve certain pharmaceutical and cosmetic preparations.

Safety and Toxicity Considerations

In regulated topical and oral (gargle, not swallowed) applications, alum is generally safe. However, ingestion of large quantities can cause gastrointestinal irritation, nausea, vomiting, and systemic aluminum accumulation. Chronic aluminum exposure has been associated with neurotoxicity and osteomalacia, particularly in patients with renal impairment. The European Food Safety Authority has set a tolerable weekly intake for aluminum of 1 mg/kg body weight. While topical alum is minimally absorbed, its use on broken skin or over prolonged periods should be controlled. Modern parenteral vaccine adjuvants are composed of poorly soluble aluminum oxyhydroxide, which dissolves slowly at the injection site, and have an extensive safety record, although rare adverse effects such as macrophagic myofasciitis have been reported [9,17].

Comparative Overview of Kaolin and Alum

Parameter	Kaolin	Alum
Chemical nature	Hydrated aluminum silicate (clay)	Hydrated double sulfate salt
Primary pharmacognostic action	Adsorbent, mechanical protectant	Astringent, antiseptic, hemostatic
Solubility	Insoluble in water	Freely soluble in water
Key traditional use	Antidiarrheal, topical poultices	Styptic, oral disinfectant, anti-sweat
Modern pharmaceutical role	Excipient (diluent, suspending agent), adsorbent	Vaccine adjuvant, water flocculant, styptic agent
Major safety concern	Inhalation (kaolinosis), constipation, drug malabsorption	Systemic aluminum toxicity (chronic oral ingestion), tissue irritation

Role in Modern Pharmacognosy and Pharmaceutical Formulations

Kaolin and alum occupy a unique niche as bridges between traditional ethnomedicine and evidence-based pharmacy. In current practice, kaolin-based preparations are found in over-the-counter antidiarrheal suspensions (often combined with pectin or bismuth salts) and in high-end mineral cosmetics where its absorbent and mattifying properties are prized. Alum, as a styptic and aftershave component, remains a mainstay of personal care. More critically, aluminum adjuvants derived from alum are components of vaccines against diphtheria, tetanus, pertussis, hepatitis A and B, human papillomavirus, and others, saving millions of lives annually.

Recent research emphasizes the potential of these minerals as multifunctional excipients. Kaolin's high surface area can be exploited to stabilize amorphous drugs and delay their crystallization, while its cation-exchange capacity can be used to design taste-masked oral formulations. Alum's protein-precipitating ability is being explored for sustained-release injectables and topical hemostatic dressings for emergency trauma care. Thus, far from being relics of pre-scientific

medicine, kaolin and alum are being re-engineered for novel therapeutic applications [10,18].

FUTURE PROSPECTS:

Nano-Sized Particles for Targeted Drug Delivery

Reducing kaolin and alum to the nanoscale dramatically increases surface area and reactivity. Nano-kaolin can intercalate drugs into its interlayer galleries or adsorb them onto its external surface, enabling pH-responsive release in the gastrointestinal tract. Research has demonstrated that kaolin nanotubes can improve the oral bioavailability of poorly water-soluble drugs such as curcumin and doxorubicin. Nano-alum particles, in turn, are being engineered as carriers for vaccine antigens, enabling a more controlled antigen release and a more potent Th2-biased immune response. Such nanotechnology-based approaches hold promise for achieving site-specific drug delivery with reduced systemic toxicity [11].

Enhanced Antimicrobial and Wound-Healing Formulations

The intrinsic antimicrobial activity of alum and the adsorptive action of kaolin can be synergistically enhanced by functionalizing the mineral surfaces with silver, copper, or zinc nanoparticles. Nano-kaolin–silver composites have shown broad-spectrum antibacterial efficacy against methicillin-resistant *Staphylococcus aureus* (MRSA) and *Pseudomonas aeruginosa*. Composite wound dressings that combine kaolin (to absorb exudates) and alum (to provide astringency and hemostasis) are currently under development for the management of chronic ulcers and burns. Such mineral-based dressings could reduce reliance on topical antibiotics and mitigate antimicrobial resistance.

Integration into Standardized Herbal–Mineral Formulations

Traditional systems have long utilized *bhasmas* (calcined metals/minerals) and mineral-herbal combinations. Scientific evaluation of these formulations can identify synergistic interactions. For instance, incorporating kaolin into an herbal antidiarrheal syrup containing *Holarrhena antidysenterica* may improve its adsorptive and stabilizing properties. Similarly, combining alum with tannin-rich herbal extracts (e.g., oak bark, *Hamamelis virginiana*) could produce a superior astringent gel for hemorrhoids. Rigorous phytochemical and pharmacological validation of such combinations can create intellectual property-protected, safe, and effective phytopharmaceuticals.

Standardization and Quality Control

The advancement of kaolin and alum into regulated therapeutic products demands robust pharmacopoeial standards. Future work must establish:

- Validated methods for particle size distribution (laser diffraction), specific surface area (BET nitrogen adsorption), and morphology (SEM/TEM).
- Quantitative mineralogical analysis using X-ray diffraction (XRD) and Fourier-transform infrared spectroscopy (FTIR).
- Stringent limits for heavy metals (lead < 10 ppm, arsenic < 2 ppm, cadmium < 1 ppm) by inductively coupled plasma mass spectrometry (ICP-MS).
- Microbial load specifications and endotoxin limits for parenteral-grade materials.

International pharmacopoeias (USP, Ph.Eur., IP) currently provide monographs only for basic kaolin and alum; nano-engineered forms and functionalized derivatives will require new, dedicated standards. Accomplishing this will increase regulatory confidence and pave the way for the inclusion of these minerals in innovative, high-value pharmaceutical products.

CONCLUSION

Kaolin and alum are classical mineral pharmacognosy agents with well-established traditional uses and clear contemporary relevance. Kaolin's adsorptive, protective, and excipient properties, and alum's astringent, antiseptic, and adjuvant actions, place them at the interface of ethnopharmacology and modern pharmaceutics. However, the transition from empirical remedies to evidence-based therapeutics demands comprehensive physicochemical characterization, rigorous toxicological assessment, and harmonized quality standards. The advent of nanotechnology and materials science offers an unprecedented opportunity to re-invent these age-old minerals as advanced drug delivery platforms and multifunctional medical devices. With concerted research and regulatory efforts, kaolin and alum can be repositioned as safe, effective, and indispensable tools in the therapeutic armamentarium of the 21st century.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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