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Beyond Fulvic Acid: A Mini-Review of the Diverse Chemical Constituents of Shilajit

Abdul Qadir[1,2], Sayed Abdur Rehman[3], Nausheen Khan[4], BDS Bedi[5], Athar Ali[6], Ashif Iqubal[*7]
[1]CEO, Herbified Healthcare, New Delhi - 110020, India
[2]Director, Herbified Research Foundation, New Delhi - 110020, India
[3]Research and Development Executive, Herbified Healthcare, New Delhi - 110020, India
[4]Director, Herbified Healthcare, Herbified Research Foundation, New Delhi, India.
[5]Chief coach, Medico Marketing Consultant, Adjoining K Area, Off Shimla Highway, Dhakoli, Zirakpur-140603, Punjab, India
[6]Associate, Hazard Communication Reckitt Benckiser (India) Pvt. Ltd. 6th & 7th Floor, Tower C, DLF Cyber Park-II, Udyog Vihar Phase-III Sector-20, Gurugram-122016 (HR)-India
[7]Research and Development Advisor, Herbified Healthcare, New Delhi-110020, India

***Correspondence: Dr. Ashif Iqubal**
Research and Development Advisor, Herbified Healthcare, New Delhi-110020, India.

ABSTRACT: Shilajit is an ancient herbo-mineral compound with diverse pharmacological properties. Preclinical and clinical studies have demonstrated powerful antioxidant, anti-inflammatory, neuroprotective, hepatoprotective, cardioprotective, anticancer, immunomodulatory, and osteogenic effects. Due to its wide-ranging health benefits and established safety, Shilajit is commonly used by both men and women as a dietary supplement. However, most published evidence emphasizes the significant role of fulvic acid as the main active component responsible for these benefits, leading consumers, manufacturers, and researchers to focus primarily on fulvic acid levels. In reality, Shilajit contains various other compounds that collectively contribute to these effects. Therefore, this manuscript aims to highlight this issue and discuss the benefits of fulvic acid alongside other related compounds. Our goal is to raise awareness among consumers, manufacturers, and researchers to look beyond fulvic acid and recognize that an optimal balance of other ingredients is also essential to harness the benefits of this natural substance fully.

KEYWORDS: Shilajit; Fulvic acid; Antioxidant; Anti-inflammatory; Natural products.

INTRODUCTION

Shilajit (or mumiyo, asphaltum, etc.) is a natural herbo-mineral resin exuding in the rocks of high altitudes (mainly in the Himalayas, Altai and other mountain ranges) [1]. In traditional medicine, it is used as a rasayana (rejuvenative tonic) in Ayurveda, Unani, Siddha medicine and others, prized in life-force, longevity and disease resistance [2–5]. In historical texts (e.g., by Razi, Biruni, Ibn Sina), the usage of Shilajit in the treatment of ailments dates to millennia. Modern science reports indicate that Shilajit is a complex of organic and inorganic compounds [6–8]. Shilajit, often described merely as a fulvic acid-rich natural substance, represents a complex biochemical matrix whose therapeutic potential extends far beyond its most studied constituent [9–11]. This mini-review discusses the various chemical components that make up Shilajit, showing that although fulvic acid rightfully claims consideration in scientific literature, the bioactivity of other compounds, such as humic acids, dibenzo-alpha-pyrone, trace minerals, polyphenols and other organic molecules, together, these components play a vital role in shaping Shilajit's broad therapeutic potential and highlight the need for thorough scientific exploration.

Chemical Constituents of Shilajit

In analytical studies, Shilajit is consistently reported to be approximately 60-80% organic matter and 20-40 % inorganic minerals by weight [12]. Humic substances (complex polymeric degradation products), in the form of humins, humic acid, and fulvic acid, represent the largest organic fraction [13]. Gallardo et al. stated that Shilajit is made predominantly out of humic substances such as fulvic acid, which make up approximately 60-80 % of all Shilajit constituents [14]. Kamgar et al. also showed that over 80 percent of the dry weight of Shilajit is humic material (predominantly fulvic and humic acids) [12]. The other organic components constitute a complex phytochemical profile: phenolic acids (e.g., ellagic, salicylic, hippuric acids), dibenzo-α-pyrones, aromatic carboxylic acids, and 3,4-benzocumarins, aliphatic lipids & fatty acids (long-chain aliphatic lipids), triterpenes and sterols, low-molecular-weight peptides/ proteins, and simple sugars [15,16]. A study using GC/MS and chromatography has found fatty acids, resinous acids, albumins, amino acids (with glycine being prominent), and phenolic lipids [17]. Simultaneously, Shilajit is a mineral-enriched material: Calcium, potassium, and magnesium normally constitute a substantial part of the inorganic portion [18]. One Study showed ~20 % of Shilajit by mass to be Ca/K/Mg salts [19]. In addition to these, tens of other trace elements and metal ions have been found (Cl, Na, P, S, Si, Al, Fe, Zn, Mn, Cu, Co, Ni, Cr, B, Ba, Sr, Ti, Se and even heavy metals such as Pb, Hg, As, Cd) [20]. Major chemical constituent of shilajit is summarized in **Figure 1,** whereas a complete chemical analysis is needed to identify all chemical compounds of shilajit.

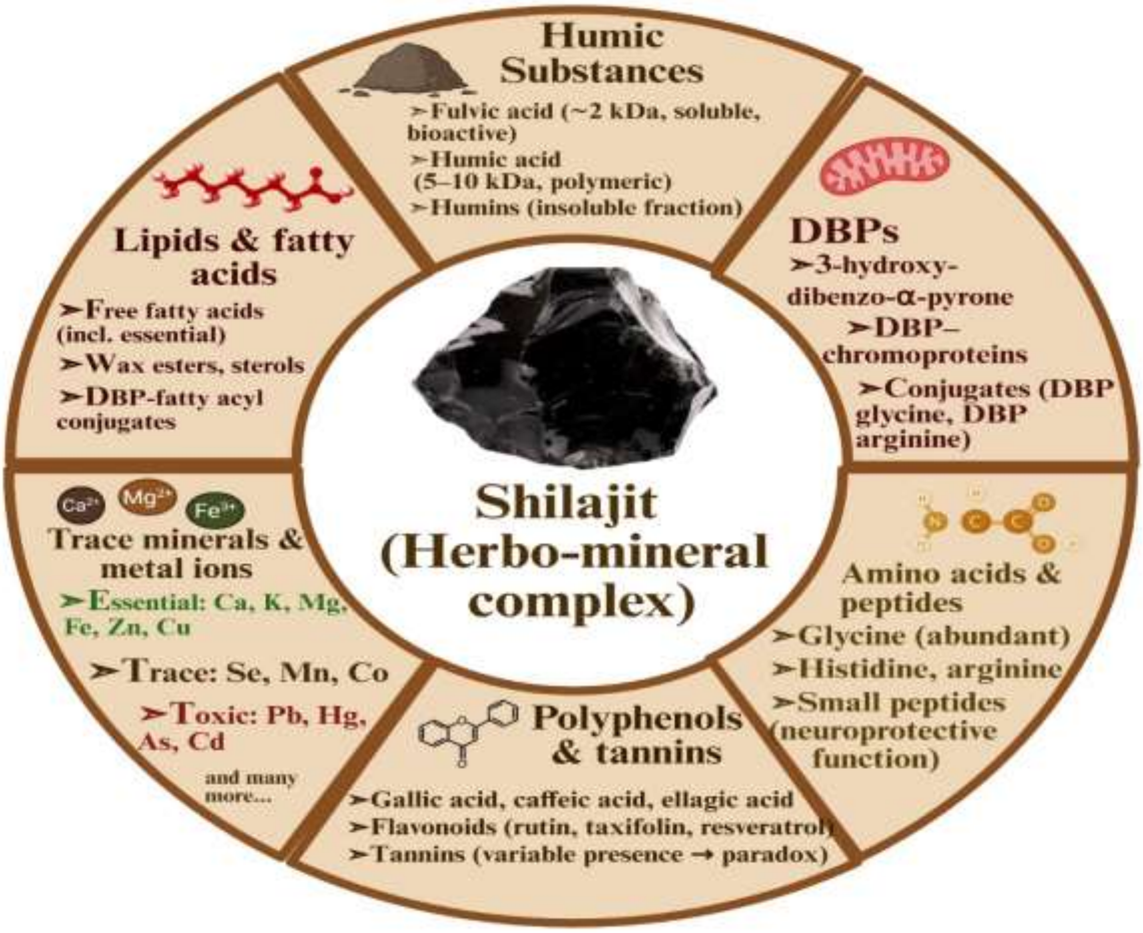

Figure 1. major chemical constituent of Shilajit (Herbo-mineral complex)

Table 1. summarizes major compound categories.

Constituent Class	Representative Compounds	Characteristics
Humic Substances	Humic acids (5–10 kDa), fulvic acid (~2 kDa)	Predominant organic matter: polyaromatic degradation products
Dibenzo-α-pyrones (DBPs)	DBPs, DBP–chromoproteins	Aromatic polyphenols: mitochondrial regulators, antioxidant
Amino Acids & Peptides	Glycine, histidine, arginine, small peptides	Proteinogenic and bioactive amino acids; neuroprotective/metabolic roles
Minerals/Ions	Ca, K, Mg (macrominerals); Fe, Zn, Cu, Mn, Se (80+ trace minerals)	Essential nutrients; enzyme cofactors; up to ~20% of Shilajit mass
Polyphenols & Tannins	Caffeic acid, gallic acid, ellagic acid, flavonoids	Antioxidant, anti-inflammatory, immunomodulatory
Lipids	Fatty acids, wax esters, triterpenes, sterols	Membrane stabilizers; anti-inflammatory; hydrophobic carriers

The exact proportions of these components can vary widely with the source. Shilajit's composition depends on its geographical and seasonal origin [21,22]. Altitude, climate, rock geology, and local flora influence which plant residues contribute to the humic matrix. For example, analyses of Himalayan vs. Altai vs. Caucasus Shilajit show measurable differences in element profiles and organic markers [21]. As a result, standardized characterization is difficult: one critical review observed, "its chemical composition is not known with certainty. No comprehensive analysis has ever been performed" across all samples [23]. Thus, Shilajit should be viewed as a naturally complex phytocomplex rather than a single "active ingredient. It is harvested during the warm months (typically spring/summer) when the mineral pitch can flow out of mountain crevices [24]. Its components are influenced by environmental conditions such as temperature, precipitation, and microbial activity during these periods. Plants (lichens, Euphorbia spp., Trifolium, etc.) that contribute to Shilajit differ regionally, which changes the ratio of phenolics and organic acids [25]. It has also been reported to vary with season within a single geography (e.g., lipid vs. polyphenol content differing in monsoon vs dry seasons), but systematic data are limited [22]. Generally, Himalayan Shilajits are more likely to be found rich in fulvic/humic acids and trace organics, but Altai/Caucasus samples can vary in the metal content or minor phytochemicals [21]. This inconsistency highlights the fact that, in the study or the treatment, "a source of Shilajit cannot be used to replace an alternative source of Shilajit".

Fulvic Acid: The Principal Component

Fulvic acid (a low-molecular-weight humic acid) is the most studied of the constituents of Shilajit. Fulvic acid can be absorbed readily and is bioavailable as it is water-soluble at pH values [15]. It is a primary active ingredient of Shilajit due to its high antioxidant and chelating properties [26]. The findings of in vitro and animal models indicate that fulvic acid neutralizes free radicals, decreases inflammation, and shields neurons [8]. Interestingly, Carrasco-Gallardo et al. have shown that fulvic acid restrained the self-aggregation of tau protein in vitro, one of the main pathological processes in AD, indicating a neuroprotective effect [14]. Fulvic acid may induce mineral entry in cells, stabilizing membrane potential and energy transformation. Therefore, numerous clinical applications of Shilajit (cognitive enhancement, antiaging, electrolyte balance) are considered due to its fulvic acid fraction [27–29]. Nonetheless, while fulvic acid is undoubtedly important, attributing all Shilajit's effects to this molecule alone is reductionist, the remaining 40% of organics and myriad inorganics likely contribute significantly to the overall bioactivity.

Humic Acids

In addition to fulvic Shilajit also contains heavier humic fractions (usually called in aggregate humic acids and humins). These are high-molecular-weight (5-10 kDa) planar polymers that are the degradation products of soil organic matter and plants [30]. Humic acids become soluble only with high pH, thus do not get absorbed as easily, though they can be present longer in the gut milieu [18]. They also might have a part in Shilajit's sustained antioxidant and metal-chelating potential, but to a lower degree per mass than fulvic acid [31]. Humins and humic acids are present in all the Shilajit samples [23]. As an example, it has been indicated in one study that Shilajit consists of 60-80% primarily of fulvic acid and humic acid [2]. These humic substances are also sometimes capable of serving as a carrier or stabilizer of other components. Gallardo et al. showed that humic components can move various mineral substances toward their cellular targets [14]. In practice, shilajit humic acids demonstrated low immunomodulatory (comparable to soil humics) and antiviral effects (preliminary studies) [32,33]. Overall, humic acids are unrecognized, but ubiquitous Shilajit constituents that appear to regulate their total bioactivity by binding nutrients and releasing them over hours.

Dibenzo-α-Pyrones and Their Derivatives

Although much of the research on Shilajit has been focused on fulvic acid, dibenzo-alpha-pyrones (DBPs) are another category of highly researched bioactive compounds that are poorly studied and understood. These substances, especially 3-hydroxydibenzo-alpha-pyrone (3- OH-DBP) and its form 3,8-dihydroxydibenzo-alpha-pyrone (3,8-$(OH)_2$-DBP), play a very essential role in the mitochondrial energy metabolism [34]. Bhattacharyya et al. have shown that DBPs combined with Coenzyme Q10 (CoQ10) have a strong potential to enhance mitochondrial functioning due to CoQ10 stabilization in its reduced form ($CoQH_2$) and better ATP production[35]. Their results showed that not only do DBPs directly scavenge free radicals, but they also have a synergistic effect within the cellular electron transport chain to maintain energy and redox balance within a cell using CoQ10 [35].

The mechanism of action was also clarified by Islam et al., who stated that 3-OH-DBP can be transformed under biological conditions to 3,8-$(OH)_2$-DBP and its conjugates of amino acids (of glycine and arginine) [34]. Those conjugates are also more water-soluble and possibly more bioavailable, which positively influences their therapeutic activity. The study reached a bioconversion rate of 60% and postulated that the microbial transformation of DBPs can be comparable to natural humification processes involved in the formation of Shilajit. It will highlight the biosynthetic plasticity and pharmacological applicability of Shilajit DBP derivatives [34].

Sawhney et al. investigated the neuroprotective potential of synthetic butylamine derivatives of DBPs in a Wistar rat model of sciatic nerve ligation-induced neuropathic pain. Over 14 days of treatment, the derivatives demonstrated significant improvements in pain thresholds (cold and warm allodynia) and enhanced antioxidant enzyme levels such as SOD, catalase, and GSH. The study reported that DBP derivatives significantly reduced nitrite concentration and pro-inflammatory cytokine levels, while also downregulating MAPK pathway markers like p-ERK, p-JNK, and p-38 in the sciatic nerve tissue [36]. Histopathological assessments confirmed the protective effects of these derivatives on neuronal tissue. These findings support the therapeutic potential of DBP derivatives as promising agents for the management of neuropathic pain disorders [36].

Amino Acids and Peptides

Shilajit is rich in amino acids and peptidic derivatives. Mostly free amino acids and small peptides, the proteinaceous material comprise approximately 13-17 % of shilajit by weight [23]. The amino acid composition is varied with glycine being frequently reported as particularly an abundant amino acid, but many other amino acids (proteinogenic as well as non-proteinogenic, e.g. histidine and leucine) are present [12]. Short peptides or DBP-conjugated peptides have been found in shilajit, as well [34]. This nutritional value and pharmacology of shilajit could be related to this rich blend of amino acids (since some of them are precursors of neurotransmitters) [35]. Quantitatively, proteins/peptides in shilajit are probably a consequence of the microbial breakdown of organic matter and are both exogenous plant peptide fragments and endogenous metabolic products [12].

Trace Minerals and Metal Ions

The mineral composition of shilajit is very diverse; some sources indicate that there are over 84 different minerals and a trace element in an ionic and highly bioavailable form [2]. Minerals like potassium, magnesium, calcium, iron and zinc are major essential minerals and they occur in large amounts [32]. Nevertheless, the abundance of this mineral profile is also followed by an important safety issue: the chance of being contaminated with poisonous heavy metals [37]. Raw or poorly refined shilajit may include toxic amounts of lead, arsenic, mercury, cadmium and aluminum, which is a deadly health hazard [37].

More importantly, the phytocomplex of shilajit has a natural safety system. Humic substances (fulvic and humic acids in particular) are strong natural chelating agents. They can complex with these toxic metal ions and thus are able to produce much-stabilized complex that can decrease their gastrointestinal absorption and bioavailability thereby decreasing their toxicity [38]. This brings up an important point: the safety of a shilajit product is a direct relationship between purity and integrity of its natural matrix. A useful purification process should not only destroy the gross contaminants, but it should also maintain the high level of humic substances that give such natural detoxification ability [32]. This is the reason why unprocessed shilajit is always discouraged and properly purified types are usually safe to take. Besides metal ions, the inorganic anion profile, such as chloride, sulphate, nitrate and phosphate also play a role in the shilajit chemical character and are greatly dependent on the geographical origin, determining overall properties and possible health impacts [12].

Polyphenols and Tannins

There are various types of phenolic compounds in shilajit, though they are usually a small portion of its humic acids. Recent research papers have found flavonoids and phenolic acids in shilajit. As an example, a HPLC experiment determined the amount of rutin (~29 ug/g), ferulic acid (~25 ug/g), resveratrol (~41 ug/g) and a high concentration of taxifolin (~532 ug/g) in a Himalayan shilajit sample [39]. These compounds are known for their antioxidant, anti-inflammatory, and cell-protective properties, acting as auxiliary agents that support the primary bioactivities of the humic and DBP fractions [40]. Caffeic acid, gallic acid and other straight forward phenolics are also reported in earlier reviews [23]. Some screenings have reported tannins (high-molecular-weight polyphenols) but the data are scarce [41]. Collectively, these phenolic compounds are probable causes of the antioxidant effect of shilajit. Conversely, other detailed phytochemical screenings have clearly stated the total absence of tannins in their samples. This contrasting disparity, what can be called the tannin paradox, is an effective microcosm of the main problems of shilajit studies [16]. The contradictory outcomes are not likely to be merely incidents; instead, they are probably connected with a complex of factors such as: 1) such profound geographic variability as the precursor plants may be rich in tannins in one area and unrich in another area; 2) the sensitivity and selectivity of the applied analytical methods, which might eliminate or degrade tannins; and 3) and processing and purification techniques that might remove or degrade tannins. This paradox highlights the urgent necessity of standardized protocol in sourcing, processing and analysis to develop a consistent and reliable chemical profile of shilajit.

Lipids and Fatty Acids

Shilajit also contains a small, but significant lipid fraction. The material normally consists of lipids (waxes and fatty acids) that make up ~4-5%. Lipidic components are free fatty acids (including essential fatty acids), waxy hydrocarbons and sterols [23]. As an example, one source in its list of the detected compounds includes such as hydrocarbons, fatty acids, and the raw resin is reported to have essential fatty acids and waxes. Also, as mentioned above, not all the shilajit DBP molecules are not acylated by fatty acids (they are DBP fatty-acyl conjugates) [36]. These fats are probably needed to dissolve organic constituents and potentially to have a bioavailability effect (shilajit extracts are frequently semi-ethanolic to extract these oily substances) [42].

Analytical Techniques Used for Characterization

The chemical complexity of shilajit has increasingly been revealed using advanced analytical instrumentation that is giving detailed information about the molecular, elemental, and structural aspects. High-Performance Liquid Chromatography (HPLC), Gas Chromatography-Mass Spectrometry (GC-MS), and Liquid Chromatography-Mass Spectrometry (LC-MS) and Liquid Chromatography-High Resolution Electrospray Ionization Mass Spectrometry (LC-HRESIMS) in particular, are central to the profiling of small molecules, allowing the detection of polyphenols (rutin, ferulic acid, resveratrol, taxifolin), dibenzo-α-pyrones (DBPs), fatty acids, phenolic acids, naphsilajit one, and even steroidal compounds [16,39,43–45]. High-Performance Size-Exclusion Chromatography (HP-SEC) also provides results of distinct high-molecular-weight polymers, such as lignin-like materials and polysaccharides [15]. The humic/fulvic character of shilajit is verified by Fourier-Transform Infrared Spectroscopy (FTIR) and Ultraviolet-Visible Spectroscopy (UV-Vis) that identify the functional groups, such as hydroxyl, carbonyl, and aromatic rings, and Nuclear Magnetic Resonance (NMR) spectroscopy, which gives structural resolution of aliphatic, heteroatom-linked, and aromatic protons and proposes the existence of polysaccharide-like structures [46,47]. The essential minerals (K, Ca, Mg, Na, Fe, P, S) and trace heavy metals (Pb, As, Hg) are all quantified in Inductively Coupled Plasma-Mass Spectrometry (ICP-MS), Inductively Coupled Plasma-Optical Emission Spectroscopy (ICP-OES), Atomic Absorption Spectroscopy (AAS), Laser-Induced Breakdown Spectroscopy [37]. (LIBS), and Scanning Electron Microscopy-Energy Dispersive X-ray Spectroscopy Complementary methods such as X-Ray Diffraction (XRD) assess its largely amorphous state with occasional crystalline mineral or lipid components [48]. This multi-dimensional profiling (which involves chromatographic, spectrometric and spectroscopic techniques) provides a high-resolution chemical fingerprint of shilajit, and more characterization can be achieved by metabolomics and more advanced NMR characterization.

Challenges and Future Perspectives

Shilajit research has a considerable challenge despite its long traditional usage. The primary ones include variability and standardization like shilajit produced in various regions (Himalayas, Caucasus, Altai, etc.) may differ significantly in composition and activity. In fact, sources caution that the health benefits of shilajit vary according to its area of origin. This heterogeneity renders reproducibility problematic, and it becomes hard to determine a single shilajit signature. Moreover, the chemical composition of shilajit remains poorly known: according to one of the recent reviews, no extensive chemical analysis has ever been carried out to identify all the chemicals and species present in shilajit. That is, after a millennium of use, we still do not have a definitive map of the chemical constituent of shilajit. There are also concerns of quality and safety. Some shilajit products have been reported contaminated with heavy metals (Pb, Hg, As, Ni, Tl, etc.) and molds. To ensure safety stringent tests and standards are required. Scientifically, the biosynthetic origin of many shilajit constituents is not clear (plant origin vs. microbial transformation), so it is not known how to standardize or classify shilajit-like extracts. Also, although in vitro and small-scale studies suggest bioactivities (antioxidant, neuroprotective, adaptogenic) there are still no large clinical trials. The research gaps need to be addressed in future. More extensive profiling (advanced analytical chemistry, untargeted LC-MS/MS, NMR metabolomics, etc.) can fully catalog the constituents of shilajit. Genome and microbiome investigations could clarify the role of alpine microbes in shilajit formation. Lastly, controlled animal and human experiments are required to attribute elements (not just fulvic acid) to clinical outcomes. With this, the extensive chemical diversity of shilajit including DBPs to trace minerals may be used more stringently to health advantage, whilst maintaining purity and efficacy in contemporary applications.

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