## Supplementary Information

# Covalent organic frameworks as superior adsorbents for the removal of toxic substances

Yubo Li,†*[a,b,c] Jinxia Wei,†[a,b] Jian Wang,†[e] Yuanyuan Wang,[a] Peishuang Yu,[a] Yao Chen*[d,e] and Zhenjie Zhang*[f]

[a] *School of Chinese Materia Medica, Tianjin University of Traditional Chinese Medicine, Tianjin 301617, China, E-mail: yaowufenxi001@sina.com.*

[b] *State Key Laboratory of Chinese Medicine Modernization, Tianjin University of Traditional Chinese Medicine, Tianjin, 301617, China.*

[c] *Haihe Laboratory of Modern Chinese Medicine, Tianjin, 301617, China.*

[d] *Key Laboratory of Biopharmaceutical Preparation and Delivery, Chinese Academy of Sciences, Beijing, 100190, China.*

[e] *State Key Laboratory of Medicinal Chemical Biology, College of Pharmacy, Nankai University, Tianjin 300071, China, E-mail: chenyao@nankai.edu.cn.*

[f] *College of Chemistry, Nankai University, Tianjin 300071, China, E-mail: zhangzhenjie@nankai.edu.cn.*

† These authors contributed equally to this work.

* Corresponding authors.

**Table S1** Properties and pathogenesis of typical toxicants

| Type of toxicants | Toxicants | Physical and chemical properties | Toxicity endpoint or target sites | Toxic mechanism | Ref. |
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| animal | Urea | - An organic compound that amide exhibits two $–NH_2$ groups<br>- Water soluble<br>- Four hydrogen donor sites | - Chronic kidney disease<br>- Uremia<br>- Cardiovascular disease<br>- Depression<br>- Diabetes mellitus | - Cause excessive formation of neutrophil extracellular traps, leading to endothelial cell dysfunction<br>- Induce mitochondrial reactive oxygen species (ROS), thereby inhibiting GAPDH, inactivating the anti-atherogenic enzyme PGI2 synthase and causing ER stress<br>- Urea or cyanate carbamylates mTOR to inhibit the mTORC1-S6K dependent dendritic protein synthesis, causing depression-like behavior | 1-4 |
| | Creatinine (CR) | - Nitrogen-containing small molecule toxin<br>- Water soluble<br>- Two hydrogen donor sites | - Uremia<br>- Renal failure | - Decrease glomerular filtration rate<br>- Accumulation in the body, accelerate the decline of renal function | 1 |
| | Uric acid (UA) | - Namely trioxopurine<br>- Water soluble<br>- Alcoholic form is weakly acidic | - Uremia<br>- Chronic kidney disease<br>- Gout | - When the level of UA in the blood is high, UA crystals form, which accumulate in the joints and kidney, causing arthritis, gout and uremia<br>- Increase oxidative stress and endothelial dysfunction | 1,5 |

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| | Indoxyl sulfate (IS) | - High protein-binding properties<br>- 32% of IS can be cleared by dialysis<br>- Fold change (M/N): 43.2 | - Nephrotoxicity<br>- Cardiovascular toxicity<br>- Disordered bone metabolism<br>- Intestinal barrier injury | - ROS production and induction of oxidative stress and renal interstitial fibrosis/inflammation<br>- Increase transcription factors expression, promote thrombosis and cause damage to cardiovascular system<br>- IS-induced oxidative stress in osteoblasts initiates the dysregulation of bone remodeling process in early CKD<br>- IS suppressed transepithelial electrical resistance and the expressions of tight junction-related genes in intestinal epithelial cells, inhibited the expression of dynamin-related protein 1 (DRP1) and mitophagic flux | 6-9 |
| | Amyloid-β peptide (Aβ) | - The length of the Aβ peptide varies from 38-43 amino acids<br>- The predominant form of Aβ peptide is $A\beta_{40}$ and $A\beta_{42}$ | - Neurotoxicity<br>- Alzheimer's disease (AD) | - Regulate apoptosis-related genes, induce neuronal apoptosis<br>- Induce inflammatory cascade response by activating microglia<br>- Induce abnormal elevations in glutamate levels, disrupt intracellular calcium balance, impair mitochondria dysfunction, and trigger oxidative stress, leading to protein and lipid oxidation | 10,11 |
| | Aflatoxins (AFs) | - Derivatives of difuran-coumarin<br>- Almost insoluble in water, but soluble in most organic solvents<br>- High thermal stability | - Hepatotoxicity<br>- Immunotoxicity<br>- Carcinogenicity<br>- Teratogenic and mutagenic effect<br>- Genotoxicity<br>- Complications associated with malnutrition<br>- Developmental delay | - AFs are metabolized under the action of cytochrome P450 microsomal enzymes, especially $AFB_1$ is converted into aflatoxin-8,9-epoxide that combines with DNA and albumin in serum to form adducts, ultimately leading to DNA damage<br>- Modulation of cytokine expression<br>- Alter intestine integrity | 12-14 |

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| | Patulin (PAT) | - An unsaturated heterocyclic lactone mycotoxin | - Genotoxicity<br>- Neurotoxicity<br>- Carcinogenicity<br>- Teratogenicity<br>- Mutagenicity<br>- Immunotoxicity<br>- Hepatotoxicity<br>- Nephrotoxicity<br>- Intestinal toxicity | - Cause damage to protein activity or function through the reaction of electrophilic groups on PAT with sulfhydryl groups on protein molecules or enzyme active sites<br>- Inhibit a variety of enzyme activities<br>- Induce DNA strand cross-linking, DNA double-strand breakage and oxidative damage | 15-18 |
| | Microcystins (MCs) | - Monocyclic heptapeptide substances<br>- Molecular structure contains carboxyl, amino, and amide groups | - Acute hepatotoxicity<br>- Liver cancer<br>- Neurotoxicity<br>- Multi-organ toxicity | - Inhibit protein phosphatase 1 and 2A<br>- Inhibit hyperphosphorylation caused by protein phosphatase, leading to severe liver injury<br>- Oxidative stress, etc<br>- Cross blood-brain barrier with the transport of Oatps/OATPs, causing neurostructural, functional, and behavioral changes | 19-22 |
| Marine toxins | Okadaic acid (OA) | - A polyketide and polyether derivative of a $C_{38}$ fatty acid<br>- A lipophilic toxin (LogP = 4.21) with hydroxyl, polycyclic ether, and carboxyl groups | - Diarrhetic shellfish poisoning<br>- Neurotoxicity<br>- Embryotoxicity<br>- Immunotoxicity<br>- Genotoxicity | - Induce secretory diarrhea by disrupting the electrolyte balance of the intestinal epithelial barrier<br>- Cause protein hyperphosphorylation to disrupt cellular biological function<br>- Inhibition of serine/threonine protein phosphatases (PPs), particularly of PP1 and PP2A | 23-25 |

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| Phytotoxins | Aristolochic acids (AAs) | - One kind of nitrophenanthrene carboxylic acids<br>- Mainly exists in the form of anions in nature | - Strong carcinogenicity<br>- Nephrotoxicity<br>- Ovarian dysfunction | - Enzymatic metabolization of AA leading to the formation of DNA adducts and induction of Tp53 mutations<br>- Induce oxidative/nitrosative reactive stress and mitochondrial dysfunction<br>- Induction of apoptosis and inflammatory response<br>- Trigger ovarian dysfunction by activating NLRP3 inflammasome and affecting mitochondrial homeostasis | 26-28 |
| | Hg(II) | - The most common form of Hg in the aqueous phase<br>- More stable<br>- Highly toxic<br>- Unable to be biodegraded | - Gastrointestinal ulcer<br>- Central nervous system injury<br>- Renal injury<br>- Hepatotoxicity | - ROS production, lipid peroxidation, induce oxidative stress<br>- Connect to the sulfhydryl groups on metallothionein, erythrocytes, or glutathione<br>- Promote depolarization of inner mitochondrial membrane and enhanced production of $H_2O_2$<br>- Enzyme inhibition<br>- Reduction of aquaporin mRNA | 29,30 |
| | Pb(II) | - A main existing form of Pb<br>- Bioaccumulation and non-biodegradability<br>- Highly toxic | - Carcinogenicity<br>- Neurological diseases<br>- Multi-organ damage, such as brain, heart, lungs, liver, blood, digestive, kidney reproductive and immune systems<br>- Genotoxicity | - Cause DNA damage, chromosomal abnormalities<br>- Induce posttranslational alterations to protein structure<br>- ROS oxidative damage, increasing the levels of lipid peroxidation<br>- Activation of glial cells, increasing inflammatory cytokines (IL-1β, TNF-α and IL-6) and serum ET-1, NO and EPO<br>- Inhibit heme biosynthesis | 29-31 |

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| As(III)<br>As(V) | - As(III) and As(V) are the main inorganic As species<br>- As(III) has higher fluidity and toxicity, more than 60 times that of As(V)<br>- As(V) is the thermos-dynamically stable form in oxygenated aqueous environments, while As(III) is generally stable under moderately reducing conditions | - Cardiovascular disease<br>- Gastrointestinal disorders<br>- Central nervous system injury<br>- Renal insufficiency<br>- Hepatotoxicity<br>- Carcinogenicity<br>- Skin damage | - Thiol binding (GSH conjugation)<br>- Cause oxidative stress, inflammation, DNA damage, mitochondrial dysfunction<br>- Neurotransmitter homeostasis and molecular alterations<br>- Decreased the activity of serum cholinesterase, mitochondrial enzymes and uncoupling of oxidative phosphorylation | 29,30,32,33 |
| Cd(II) | - Cd exists as Cd(II) in the natural environment<br>- Highly soluble<br>- Highly toxic<br>- Bioaccumulation and non-biodegradability | - Testicular damage<br>- Fulminant hepatitis<br>- Pulmonary edema<br>- Hemorrhage<br>- Kidney and liver damage<br>- Brain and bone toxicity<br>- Autoimmune<br>- Genotoxicity and cancer | - Cause apoptosis<br>- ROS generation and oxidative stress development<br>- Aberrant gene expression<br>- Endoplasmic reticulum stress<br>- Disturb the DNA synthesis and DNA repair by the proteotoxicity and DNA damage induced by oxidative stress<br>- Alter phosphorylation cascades | 29,30,34 |

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| Cr(VI) | - A strong oxidant with a high positive charge and a small radius<br>- Mainly in the form of anions such as $CrO_4^{2-}$, $Cr_2O_7^{2-}$, and $HCrO_4^-$ | - Renal insufficiency<br>- Gastrointestinal disorders<br>- Skin disorders<br>- Increase the incidence of many cancers<br>- Respiratory, immune, cardiovascular, nervous and reproductive system damage<br>- Genotoxicity | - ROS generation and cause oxidative stress<br>- DNA adduct formation to induce DNA damage<br>- Dysregulated cell proliferation<br>- Induce free radical production and result in DNA damage<br>- Lead to the formation of DNA-protein cross-links and Cr-DNA adducts, block DNA transcription and replication | 29,30,33,34 |
| Neonicotinoid insecticides (NEOs) | - Obtained by functional group transformation on the basis of nicotine molecular structure<br>- High water solubility<br>- Has hydrogen bond receptor and hydrogen bond donor | - Neurotoxicity<br>- Cardiovascular effects<br>- Respiratory failure<br>- Sedation and seizures<br>- Rhabdomyolysis | - Bind to nicotinic acetylcholine receptor, causing nicotinic symptoms and severe neurological damage | 35-37 |
| Triazole fungicides | - Nitrogen-containing heterocyclic compounds | - Reproductive and developmental toxicity<br>- Mutagenicity<br>- Carcinogenicity<br>- Endocrine disrupting effects<br>- Liver toxicity | - Accumulate in the liver, cause liver functional abnormalities and metabolic disorders<br>- Interfere with lipid metabolism by binding to nuclear receptors (peroxisome proliferator-activated receptors and retinoid X receptor)<br>- Interfere with estrogen-induced signal transduction | 38,39 |

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| Organophosphorus pesticides (OPPs) | - Most of them are phosphate or phosphorothioate esters<br>- $R_1$ and $R_2$ in their structural formulas are mostly methoxy ($CH_3O^-$) or ethoxy ($C_2H_5O^-$) | - Various neurological disorders, such as AD, Parkinson's disease, and other neurotoxicity<br>- Metabolic diseases, e.g. diabetes, hyperlipidemia<br>- Hepatic toxicity<br>- Renal insufficiency<br>- Cardiopulmonary toxicity<br>- Immunotoxicity<br>- Genotoxicity<br>- Endocrine toxicity<br>- Neurotoxicity<br>- Hepatotoxicity<br>- Nephrotoxicity<br>- Reproductive toxicity<br>- Neurodegenerative effects<br>- Endocrine system changes<br>- Carcinogenicity | - Irreversibly bind to acetylcholinesterase<br>- Cause oxidative stress, reduce the membrane potential of mitochondria, leading to mitochondrial DNA mutations<br>- Inflammation response | 40,41 |
| Fipronil | - Phenylpyrazole chemicals | | - Interfere with GABA-gated channels and disrupt normal neuronal influx by targeting GABA-gated chloride channels<br>- Inhibit human $\alpha_1$, $\alpha_1\beta$, $\alpha_2$, and $\alpha_3$ glycine receptor subtypes | 42,43 |
| Trifluralin | - Fluorinated dinitroaniline<br>- Low water solubility (lipophilic) | - Cytotoxicity<br>- Genotoxicity | - Inhibition of $Ca^{2+}$ transport mechanisms at the plasmatic membrane<br>- Activate the oxidative stress pathway and chromosomal damage<br>- Mild mitochondrial dysfunction, mitophagy, or inhibition of proliferation<br>- Alter the expression levels of cancer-related genes | 44,45 |

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| Radionuclides | Iodine (I) | - Strong volatility and high diffusion coefficient<br>- $^{129}I$ and $^{131}I$ are the two main radionuclides of iodine<br>- Form polyiodides in an aqueous medium<br>- The most common are the triiodide ions | - Thyroid cancer<br>- Unconsciousness | - Accumulate in the thyroid gland and interfere metabolic system | 46,47 |
| | Uranium (U) | - U(VI) has strong fluidity, high radioactivity and high toxicity<br>- U(IV) is less soluble and relatively immobile | - Severe kidney injury<br>- Pulmonary toxicity<br>- Other organs damage, mainly hepatic, hematopoietic, neurological, and reproductive effects | - Oxidative stress<br>- Genetic damage<br>- Protein injury<br>- Cell apoptosis<br>- Inflammation<br>- Metabolic disorders | 48,49 |
| | Technetium (Tc) | - Exist in the form of pertechnetate anion ($TcO_4^-$)<br>- High water solubility<br>- Extremely high mobility | - Radiation damage | - Radiation causes ionization and stimulation of intracellular molecules, disrupting the normal functioning of biological organisms<br>- Cause ionization or excitation of biological macromolecules and proteins, resulting in structural changes and loss of activity | 50,51 |

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| Others | Chlorination disinfection by-products (Cl-DBPs) | - Include aliphatic and aromatic DBPs<br>- Aromatic DBPs are more toxic than many aliphatic DBPs | - Colorectal cancer<br>- Bladder, stomach, lymphoma, kidney, pancreas, breast, and oesophagus cancer<br>- Birth defects<br>- Stillbirths and spontaneous abortions<br>- Genotoxicity<br>- Cytotoxicity<br>- Teratogenicity and endocrine disruption<br>- Neurotoxicity | - Modulate various signaling pathways, leading to endocrine disorders and DNA damage, mimicking or antagonizing endogenous hormones | 52-54 |
| | Perfluoroalkyl and polyfluoroalkyl substances (PFASs) | - Perfluoroalkyl is fully fluorine<br>-Polyfluoroalkyl substances have a non-fluorine atom attached to at least one carbon atom | - Harmful endocrine effects:<br>- Thyroid disease<br>- Hepatoxicity<br>- Immunotoxicity<br>- Neurotoxicity<br>- Reproduction and development toxicity<br>- Carcinotoxicity | - Disturb steroidogenesis<br>- Interfere with steroid hormone receptors<br>- PFAS is proved to be both PPARα and CAR agonist, causing toxicity<br>- Changes in lipid metabolism<br>- Oxidative stress<br>- Result in altered androgen and insulin-like factor 3 (INSL3) dependent processes | 55,56 |

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