Undergraduate Certificate in Toxicology of Plants

Plant Toxicology Principles

Acephate - related: Organophosphate, insecticide a systemic organophosphate that inhibits acetylcholinesterase in herbivorous insects and mammals. Example: Used on citrus to control leaf-miners. Practical application includes field trials for dose-response. Challenge: High toxicity to non-target pollinators and rapid degradation in soil limiting efficacy.

Aconitine - related: Alkaloid, aconite a potent neurotoxin from Aconitum species that binds voltage-gated sodium channels, causing persistent activation. Example: Accidental poisoning from wild herbs. Application: Used as a reference standard in bioassays for sodium-channel blockers. Challenge: Narrow therapeutic index and poor stability in aqueous solutions.

Acute toxicity - related: LD50, dose-response the adverse effect occurring shortly after a single exposure, measured by lethal dose for 50 % of test organisms. Example: Acute LD50 of ricin in mice. Practical use: Regulatory classification of pesticides. Challenge: Extrapolating acute data to chronic human risk.

Adverse outcome pathway (AOP) - related: Mechanistic framework, key event a structured sequence linking a molecular initiating event to an adverse ecological effect. Example: Inhibition of photosystem II leading to reduced primary productivity. Application: Predictive modeling for risk assessment. Challenge: Data gaps at intermediate key events.

Alkaloid - related: Secondary metabolite, nitrogenous a class of nitrogen-containing natural products with diverse pharmacological actions. Example: Nicotine from Nicotiana tabacum acts on nicotinic acetylcholine receptors. Practical use: Screening plant extracts for insecticidal activity. Challenge: Structural diversity complicates analytical quantification.

Allelopathy - related: Phytotoxin, plant-plant interaction the release of chemical compounds by one plant that affect the growth or development of neighboring species. Example: Juglone from black walnut suppresses many herbaceous seedlings. Application: Developing natural weed-control agents. Challenge: Environmental variability influencing compound persistence.

Allergenicity - related: Hypersensitivity, pollen the capacity of a plant protein or metabolite to trigger immune responses in susceptible individuals. Example: Profilin from birch pollen causing cross-reactivity with fruit allergens. Practical relevance: Labeling of botanical supplements. Challenge: Limited predictive assays for novel plant proteins.

Amygdalin - related: Cyanogenic glycoside, apricot a glycoside that releases hydrogen cyanide upon hydrolysis. Example: Present in bitter almond and apricot kernels. Application: Used in studies of cyanide detoxification pathways. Challenge: Ethical concerns over “vitamin B17” claims and potential poisoning.

Anthocyanin - related: Flavonoid, pigment water-soluble pigments responsible for red, purple, and blue colors in many fruits and leaves. Example: Cyanidin-3-glucoside in blueberry. Practical use: Marker for

oxidative stress in plant bioassays. Challenge: Stability under varying pH and light conditions.

Anthraquinone - related: Laxative, dye a class of aromatic compounds with a quinone core, some of which are toxic to livestock. Example: Emodin from Rheum species. Application: Screening for plant-derived antimicrobial agents. Challenge: Distinguishing between beneficial and harmful analogues.

Apoptosis - related: Programmed cell death, caspase a regulated cellular process that can be triggered by plant toxins affecting mitochondrial pathways. Example: Ricin inducing apoptosis in hepatic cells. Practical relevance: Assessing cytotoxicity of extracts. Challenge: Differentiating apoptosis from necrosis in in-vitro assays.

Arsenic phytoremediation - related: Hyperaccumulator, Pteris vittata the use of certain ferns to extract arsenic from contaminated soils. Example: Field trials in former mining sites. Application: Low-cost cleanup of polluted lands. Challenge: Disposal of arsenic-rich biomass and variable uptake rates.

Artemisinin - related: Sesquiterpene lactone, antimalarial a potent endoperoxide compound from Artemisia annua that generates reactive oxygen species in parasites. Example: Commercial extraction for antimalarial drugs. Practical use: Model for plant-derived drug discovery. Challenge: Resistance development and supply chain sustainability.

Atrazine - related: Herbicide, triazine a synthetic herbicide that inhibits photosystem II, leading to reduced electron transport. Example: Widespread use in corn production. Application: Reference toxicant in aquatic toxicity tests. Challenge: Chronic exposure effects on amphibian development.

Auto-toxicity - related: Self-poisoning, autotoxic compounds the phenomenon where a plant releases compounds that inhibit its own growth. Example: Phenolic acids from root exudates of wheat. Practical relevance: Crop rotation planning. Challenge: Quantifying autotoxic effects in field conditions.

Azadirachtin - related: Neem, insect growth regulator a complex limonoid from Azadirachta indica that interferes with insect molting hormones. Example: Commercial neem oil formulations. Application: Integrated pest management (IPM). Challenge: Variability in composition due to extraction method.

Barbiturates (plant origin) - related: Sedative, GABA rare plant-derived compounds that modulate the GABA-A receptor. Example: Barbital-like substances isolated from certain fungi associated with plants. Practical use: Pharmacological screening. Challenge: Low natural abundance and synthesis difficulty.

Benzoic acid derivatives - related: Sorbic acid, preservative phenolic acids produced by many plants with antimicrobial properties. Example: Benzoic acid in cranberries inhibiting bacterial growth. Application: Natural food preservative testing. Challenge: Rapid metabolism in mammals reducing efficacy.

Betalains - related: Pigment, betalainic nitrogen-containing pigments giving red-violet color to beets and some cactus fruits. Example: Betanin used as a food colorant. Practical relevance: Indicator of oxidative stress in plant tissues. Challenge: Instability at high temperature and pH extremes.

Bioaccumulation factor (BAF) - related: Biomagnification, trophic transfer ratio of a substance's concentration in an organism to that in the surrounding environment. Example: BAF of cadmium in lettuce.

Application: Risk assessment for food safety. Challenge: Variability due to plant genotype and soil chemistry.

Biodegradation - related: Microbial metabolism, mineralization the breakdown of plant toxins by microorganisms into less harmful products. Example: Bacterial degradation of atrazine in soil. Practical use: Bioremediation strategies. Challenge: Incomplete degradation leading to toxic metabolites.

Biomonitoring - related: Sentinel species, indicator the use of plants to assess environmental contamination levels. Example: Monitoring heavy metals using Brassica species. Application: Early warning system for polluted sites. Challenge: Distinguishing between uptake from soil versus atmospheric deposition.

Biopesticide - related: Microbial insecticide, botanical a pesticide derived from natural organisms or their metabolites. Example: Bacillus thuringiensis (Bt) toxins targeting Lepidoptera. Practical relevance: Reducing synthetic chemical load. Challenge: Resistance development and formulation stability.

Blanching - related: Processing, toxin reduction a heat treatment that inactivates enzymes and reduces certain plant toxins. Example: Blanching spinach to lower oxalic acid content. Application: Food safety protocols. Challenge: Nutrient loss alongside toxin reduction.

Botanical nomenclature - related: Taxonomy, binomial the standardized system for naming plant species. Example: *Ricinus communis* for the castor bean. Practical relevance: Accurate identification of toxic species in surveys. Challenge: Synonymy and taxonomic revisions.

Brassinosteroids - related: Plant hormone, growth regulator a class of polyhydroxylated steroids influencing cell elongation and stress responses. Example: Application improves tolerance to salinity. Practical use: Evaluating cross-talk with toxin-induced pathways. Challenge: Low natural concentrations complicate detection.

Broadleaf herbicide - related: Selective, 2,4-D chemicals targeting dicotyledonous weeds while sparing grasses. Example: 2,4-D used in cereal crops. Application: Field efficacy studies. Challenge: Off-target drift affecting non-target flora.

Brown rot - related: Fungal disease, decay a wood-decaying process caused by fungi that secrete oxalic acid, which can be toxic to surrounding vegetation. Example: *Serpula lacrymans* in timber structures. Practical relevance: Assessing indirect plant toxicity from decay products. Challenge: Detecting sub-lethal effects on neighboring plants.

Cadmium phytotoxicity - related: Heavy metal, oxidative stress the detrimental impact of cadmium on plant growth, photosynthesis, and enzyme activity. Example: Reduced root elongation in rice exposed to 10 µM Cd. Application: Screening tolerant cultivars. Challenge: Interactions with essential nutrients like Zn.

Calcium oxalate crystals - related: Raphides, defense needle-shaped crystals that can cause irritation when plant tissue is damaged. Example: Raphides in *Dieffenbachia* cause oral burning. Practical use: Forensic identification of plant exposure. Challenge: Variability in crystal density among species.

Carcinogenicity - related: Mutagenicity, long-term risk the potential of a substance to induce cancer after prolonged exposure. Example: Aflatoxin B1 from *Aspergillus* on crops. Application: Regulatory limits for

food safety. Challenge: Species-specific metabolic activation pathways.

Cation exchange capacity (CEC) - related: Soil chemistry, nutrient retention a measure of how many cations a soil can retain, influencing the mobility of metal-based plant toxins. Example: High CEC soils immobilize lead, reducing uptake. Practical relevance: Site-specific risk assessments. Challenge: Temporal changes due to organic matter turnover.

Cell wall lignification - related: Structural polymer, resistance the deposition of lignin in cell walls, which can impede the movement of water-soluble toxins. Example: Increased lignin in *Populus* reduces uptake of herbicides. Application: Breeding for reduced toxin translocation. Challenge: Trade-off with growth rate.

Centromere - related: Chromosome, genetic stability the region of a chromosome that ensures proper segregation during cell division; certain plant toxins can cause chromosomal aberrations at the centromere. Example: Colchicine disrupts microtubules leading to polyploidy. Practical use: Generating doubled haploids. Challenge: Unintended genome instability.

Chemotaxis - related: Movement, attractant directed movement of organisms toward or away from chemical stimuli; some plant toxins act as repellents for soil nematodes. Example: Glucosinolate breakdown products deter root-feeding insects. Application: Designing crop rotations. Challenge: Species-specific responses.

Chlorophyll fluorescence - related: Photosynthetic efficiency, stress indicator a non-invasive technique measuring the re-emission of light by chlorophyll, useful for detecting early toxin-induced photosystem damage. Example: Decline in Fv/Fm after atrazine exposure. Practical relevance: Rapid screening of herbicide residues. Challenge: Environmental light variability affecting measurements.

Chromatography (HPLC, GC) - related: Analytical, separation core techniques for separating and quantifying plant toxins. Example: HPLC-UV for detecting pyrrolizidine alkaloids in honey. Application: Regulatory compliance testing. Challenge: Matrix interferences requiring extensive sample cleanup.

Circadian regulation - related: Clock genes, metabolism the internal timing system influencing toxin biosynthesis and detoxification pathways. Example: Peak production of cyanogenic glycosides at night in *Cassava*. Practical use: Timing of harvest to minimize toxin levels. Challenge: Genetic variation in clock gene expression.

Citric acid cycle inhibition - related: Metabolic disruption, mitochondria some plant toxins block enzymes of the TCA cycle, reducing ATP production. Example: Aconitine binding to aconitase. Application: Investigating mitochondrial toxicity in cell cultures. Challenge: Compensatory metabolic pathways obscure effects.

Claviceps purpurea - related: Ergot, alkaloid a fungal pathogen of cereals producing ergot alkaloids that cause vasoconstriction in mammals. Example: Historic ergotism outbreaks. Practical relevance: Monitoring grain for ergot bodies. Challenge: Distinguishing ergot contamination from legitimate fungal endophytes.

Co-culture assays - related: Interaction, synergism experimental setups where toxic and non-toxic plant species are grown together to assess allelopathic effects. Example: Ryegrass intercropped with *Phacelia* to

evaluate growth suppression. Application: Designing sustainable cropping systems. Challenge: Controlling for nutrient competition versus chemical interference.

Cytogenetics - related: Chromosome staining, karyotype the study of chromosome structure and behavior under toxin influence. Example: Micronucleus formation in *Allium cepa* root tips after exposure to heavy metals. Practical use: Rapid genotoxicity screening. Challenge: Scoring artefacts in high-throughput assays.

Cytotoxicity assays - related: MTT, LDH release in-vitro tests measuring cell viability after exposure to plant extracts. Example: MTT assay revealing IC50 of berberine on cancer cell lines. Application: Preliminary drug discovery. Challenge: Assay interference by colored pigments.

DNA adducts - related: Mutagenic lesions, repair covalent modifications of DNA bases formed by reactive plant metabolites. Example: Pyrrolizidine alkaloid metabolites forming adducts with guanine. Practical relevance: Biomonitoring exposed populations. Challenge: Low abundance requiring highly sensitive mass spectrometry.

Detoxification enzymes - related: GST, cytochrome P450 proteins that metabolize xenobiotics into less harmful forms. Example: Glutathione S-transferase conjugates with phenolic toxins in *Arabidopsis*. Application: Engineering crops with enhanced detox capacity. Challenge: Metabolic burden reducing growth.

Diacetyl - related: Flavor compound, respiratory toxin a volatile diketone produced by certain microbes on plant surfaces; inhalation can cause bronchiolitis obliterans. Example: Occupational exposure in popcorn factories. Practical use: Monitoring volatile emissions in post-harvest storage. Challenge: Differentiating plant-derived from microbial sources.

DIA (Data-Independent Acquisition) - related: Proteomics, mass spectrometry a technique that simultaneously records all fragment ions, facilitating comprehensive profiling of toxin-induced protein changes. Example: Evaluating proteomic shifts in *Zea mays* after fumonisin exposure. Application: Systems toxicology. Challenge: Data complexity requiring advanced bioinformatics.

Dicoumarol - related: Anticoagulant, coumarin a natural anticoagulant formed from the oxidation of coumarin in spoiled sweet clover, inhibiting vitamin K epoxide reductase. Example: Hemorrhagic disease in cattle. Practical relevance: Assessing feed safety. Challenge: Variable formation rates depending on storage conditions.

Dimethyl sulfoxide (DMSO) - related: Solvent, permeabilizer a polar aprotic solvent frequently used to dissolve hydrophobic plant toxins for bioassays. Example: Preparing stock solutions of curcumin. Application: Facilitating in-vitro testing. Challenge: Intrinsic biological activity of DMSO at higher concentrations.

Diosgenin - related: Steroidal sapogenin, precursor a plant sterol extracted from *Dioscorea* species, used as a scaffold for synthesizing corticosteroids. Example: Semi-synthetic production of progesterone. Practical use: Illustrating biotechnological value of toxic precursors. Challenge: Low natural yield necessitating large-scale cultivation.

DNA barcoding - related: Species identification, rbcL a molecular technique using short gene regions to identify plant species, crucial for confirming toxic species in mixed samples. Example: Identifying *Aconitum* in herbal products. Application: Regulatory enforcement. Challenge: Incomplete reference databases for rare taxa.

Docking simulations - related: In-silico, binding affinity computational modeling of toxin interaction with target proteins to predict toxicity mechanisms. Example: Docking ricin B-chain with galactose residues. Practical relevance: Prioritizing compounds for laboratory testing. Challenge: Accuracy limited by protein structural data.

Dolichol phosphate - related: Lipid carrier, glycosylation a membrane lipid involved in N-linked glycosylation; some plant toxins inhibit its function, disrupting protein folding. Example: Inhibition by certain trichothecenes. Application: Studying ER stress pathways. Challenge: Measuring subtle changes in glycosylation profiles.

Dosage form - related: Tablet, extract the physical preparation of a plant toxin for administration, influencing bioavailability. Example: Encapsulated *Cassava* cyanogenic glycoside extracts for controlled release studies. Practical use: Standardizing experimental exposure. Challenge: Ensuring uniform distribution of active constituents.

Dust toxicity - related: Aerosol, inhalation hazards arising from fine particulate plant material that can carry toxins. Example: Pollen grains of *Ricinus* containing ricin protein fragments. Application: Occupational health monitoring in agricultural settings. Challenge: Low concentration detection in air samples.

Ecotoxicology - related: Ecosystem, sentinel species the study of toxic effects of plant compounds on non-target organisms and ecological processes. Example: Impact of *Phragmites* allelochemicals on aquatic invertebrates. Practical relevance: Informing environmental regulations. Challenge: Integrating multi-species data into risk models.

EDTA chelation - related: Metal binding, detox a chelating agent used to sequester heavy metals in contaminated soils, reducing plant uptake. Example: EDTA amendment lowering lead levels in lettuce. Application: Remediation strategies. Challenge: Potential mobilization of metals into groundwater.

Enantioselectivity - related: Chiral toxins, stereochemistry the differential biological activity of enantiomers of a plant toxin. Example: (-)-Strychnine being more potent than (+)-strychnine. Practical use: Refining extraction to favor less toxic enantiomer. Challenge: Analytical separation of enantiomers in complex matrices.

Enzyme inhibition kinetics - related: Michaelis-Menten, IC50 quantitative assessment of how a toxin reduces enzyme activity. Example: Determining Ki for berberine inhibition of CYP2D6. Application: Predicting drug-herb interactions. Challenge: Mixed-type inhibition complicating data interpretation.

Epigenetic modulation - related: DNA methylation, histone acetylation plant toxins can alter gene expression without changing DNA sequence. Example: Demethylation of stress-responsive genes by sulforaphane. Practical relevance: Exploring long-term effects on plant progeny. Challenge: Distinguishing

direct toxin effects from secondary stress responses.

Ergosterol assay - related: Fungal biomass, toxicity measurement of ergosterol as a proxy for fungal colonization when assessing antifungal plant extracts. Example: Reduced ergosterol in *Candida* cultures treated with tea tree oil. Application: Screening botanical fungicides. Challenge: Interference from plant sterols.

Ethylenediaminetetraacetic acid (EDTA) - related: Chelator, metal toxicity see “EDTA chelation”. It is often employed in laboratory assays to prevent metal-catalyzed oxidation of toxin samples. Practical use: Preserving stability of phenolic extracts. Challenge: Residual EDTA affecting downstream bioassays.

Exogenous application - related: Foliar spray, seed treatment the deliberate addition of a plant toxin to a crop for experimental or protective purposes. Example: Foliar application of neem extract to suppress aphids. Practical relevance: Field trials of botanical pesticides. Challenge: Variability in absorption due to leaf cuticle thickness.

Fumonisin B1 - related: Mycotoxin, sphingolipid a fusarium-derived toxin that inhibits ceramide synthase, leading to disrupted sphingolipid metabolism. Example: Grain contamination causing leukoencephalomalacia in horses. Application: Setting maximum residue limits in cereals. Challenge: Detecting low-level co-contamination with other mycotoxins.

Gaultheria procumbens - related: Wintergreen, methyl salicylate a shrub producing methyl salicylate, a volatile that can cause respiratory irritation at high concentrations. Example: Occupational exposure in essential-oil distillation. Practical use: Studying plant-derived analgesics. Challenge: Managing emission levels in enclosed processing facilities.

Gene ontology (GO) analysis - related: Functional annotation, bioinformatics a method for interpreting transcriptomic changes induced by toxins, categorizing affected biological processes. Example: GO terms linked to oxidative stress after exposure to juglone. Application: Prioritizing pathways for further investigation. Challenge: Redundancy and over-representation of generic terms.

Glucosinolates - related: Mustard oil, defense sulfur-containing compounds that, upon tissue damage, hydrolyze to isothiocyanates, which are toxic to many herbivores. Example: Sulforaphane from broccoli exhibiting anticancer properties. Practical relevance: Breeding low-glucosinolate varieties for livestock feed. Challenge: Balancing pest resistance with nutritional quality.

Glycoalkaloids - related: Solanine, toxicity nitrogenous glycosides in Solanaceae plants that interfere with cell membranes. Example: A-solanine in green potatoes causing gastrointestinal distress. Application: Post-harvest monitoring for greening. Challenge: Variability in concentration due to environmental stress.

HPLC-MS/MS - related: Quantitative analysis, multiple reaction monitoring a powerful analytical platform for simultaneous detection of multiple plant toxins at trace levels. Example: Simultaneous quantification of aflatoxins, ochratoxin A, and patulin in fruit juices. Practical use: Regulatory compliance testing. Challenge: Matrix effects requiring extensive method validation.

Hemolysis assay - related: Red blood cells, cytotoxicity an in-vitro test measuring the ability of a toxin to lyse erythrocytes. Example: Saponins from *Quillaja* causing dose-dependent hemolysis. Application: Safety assessment of surfactant extracts. Challenge: Species-specific membrane composition influencing results.

Herbicide resistance - related: Target-site mutation, metabolic resistance the evolution of weed populations that survive herbicide application. Example: *Amaranthus* spp. With mutated EPSPS conferring glyphosate resistance. Practical relevance: Rotating modes of action. Challenge: Rapid spread of resistance genes via pollen flow.

Histopathology - related: Tissue morphology, lesions microscopic examination of organ damage after toxin exposure. Example: Hepatic necrosis in rats fed high-dose cassava cyanogens. Application: Confirming organ-specific toxicity. Challenge: Differentiating primary toxin effects from secondary inflammatory responses.

Hydroponic culture - related: Soilless system, controlled exposure growing plants in nutrient solutions that can be spiked with precise toxin concentrations. Example: Assessing cadmium uptake in lettuce under defined conditions. Practical use: Reproducible toxicological experiments. Challenge: Root exudate interactions altering toxin availability.

Hydrolysis - related: Enzymatic cleavage, activation the chemical breakdown of a compound by water, often converting a non-toxic precursor into a toxic metabolite. Example: Cyanogenic glycoside hydrolysis releasing HCN. Application: Timing of processing steps to minimize toxin release. Challenge: Controlling enzymatic activity during storage.

In silico modeling - related: QSAR, predictive toxicology computational approaches that estimate toxicity based on chemical structure. Example: QSAR models predicting LD50 of novel alkaloids. Practical relevance: Prioritizing compounds for synthesis. Challenge: Limited training data for rare plant toxins.

Induced systemic resistance (ISR) - related: Priming, beneficial microbes a plant’s heightened defensive state triggered by non-pathogenic microbes, sometimes enhancing tolerance to toxins. Example: *Pseudomonas fluorescens* treatment reducing phytotoxic effects of fusarium toxins. Application: Biocontrol strategies. Challenge: Variability among plant genotypes.

Isoflavones - related: Phytoestrogen, legume a class of flavonoids with estrogenic activity, potentially affecting reproductive health. Example: Genistein from soy influencing hormone pathways. Practical use: Evaluating dietary exposure risks. Challenge: Metabolic conversion to active metabolites differing among species.

Jasmonic acid pathway - related: Defense signaling, secondary metabolites a hormonal cascade activated by herbivory that often up-regulates toxin biosynthesis. Example: Increased nicotine in tobacco after insect attack. Application: Manipulating pathway to reduce toxin levels pre-harvest. Challenge: Trade-off with growth vigor.

Jasmonate-induced volatile organic compounds (VOCs) - related: Indirect defense, signaling airborne chemicals released after jasmonate signaling that can attract predators of herbivores. Example: (E)-

β-ocimene emitted by *Arabidopsis* under attack. Practical relevance: Using VOCs as biomarkers of stress. Challenge: Quantifying low-concentration emissions in field.

Kinetic isotope effect - related: Reaction mechanism, deuterium labeling the change in reaction rate when an atom in a toxin is replaced by its heavier isotope. Example: Deuterated coumarin showing slower metabolism. Application: Probing metabolic pathways of plant toxins. Challenge: Synthesis of isotopically labeled standards.

LC-Orbitrap - related: High-resolution mass spectrometry, accurate mass an analytical instrument offering sub-ppm mass accuracy for complex toxin mixtures. Example: Untargeted profiling of marine algal toxins. Practical use: Discovery of novel compounds. Challenge: Data processing demands extensive computational resources.

Lignans - related: Phytoestrogen, antioxidant phenolic dimers found in seeds and grains; some exhibit weak estrogenic activity. Example: Secoisolariciresinol in flaxseed. Application: Assessing dietary exposure. Challenge: Variability in gut microbiota influencing bioavailability.

Linkage disequilibrium - related: Genetics, association mapping non-random association of alleles at different loci, useful for locating toxin-related genes. Example: GWAS identifying loci linked to alkaloid content in *Papaver*. Practical relevance: Marker-assisted selection. Challenge: Population structure confounding signals.

Log P (octanol-water partition coefficient) - related: Lipophilicity, bioaccumulation a physicochemical property predicting a toxin's ability to cross biological membranes. Example: High Log P of dioxins correlating with persistence. Application: Screening candidates for low environmental mobility. Challenge: Exceptions due to active transport mechanisms.

Metabolomics - related: LC-MS, NMR, pathway analysis the comprehensive profiling of metabolites altered by toxin exposure. Example: Untargeted metabolomics revealing accumulation of phytate in cadmium-stressed rice. Practical use: Identifying biomarkers of exposure.

Microbial degradation - related: Biodegradation, catabolic pathways the enzymatic breakdown of plant toxins by bacteria or fungi. Example: *Pseudomonas* species degrading phenolic herbicides. Application: Developing bioaugmentation products. Challenge: Ensuring complete mineralization without accumulation of intermediate metabolites.

Mitigation strategies - related: Processing, breeding, agronomy approaches aimed at reducing toxin levels in crops. Example: Soaking cassava roots to leach cyanogenic glycosides. Practical relevance: Improving food safety. Challenge: Balancing toxin reduction with nutrient retention.

Molecular initiating event (MIE) - related: AOP, trigger the first interaction between a toxin and a biological target that starts the cascade leading to adverse effects. Example: Binding of aflatoxin B1 to DNA as the MIE for carcinogenesis. Application: Early-stage risk assessment. Challenge: Identifying MIEs for complex mixtures.

Monocot vs. Dicot sensitivity - related: Selective herbicide, physiological differences variation in susceptibility to toxins based on plant class. Example: Dicots being more sensitive to 2,4-D than monocots. Practical use: Designing selective herbicide programs. Challenge: Interspecies variability within each group.

Neurotoxicity - related: Cholinesterase inhibition, excitotoxicity adverse effects on the nervous system caused by plant toxins. Example: Tetrodotoxin from *Buxus* species blocking voltage-gated sodium channels. Application: Neuropharmacology research. Challenge: Limited in-vivo models that replicate human exposure.

Non-target effects - related: Biodiversity loss, ecosystem services unintended impacts of plant toxins or their applications on organisms not intended to be affected. Example: Bee mortality after exposure to neonicotinoid-laden pollen. Practical relevance: Ecological risk assessments. Challenge: Detecting sub-lethal effects that influence behavior.

Oxidative stress biomarkers - related: ROS, lipid peroxidation measurable indicators of cellular damage caused by reactive oxygen species generated by toxins. Example: Malondialdehyde (MDA) levels rising after copper exposure. Application: Monitoring plant health under pollutant stress. Challenge: Specificity of biomarkers to particular toxins.

Oxytetracycline residues - related: Antibiotic, plant-derived residues from using oxytetracycline as a bacterial disease control in crops, potentially contributing to antimicrobial resistance. Example: Citrus orchards treated for citrus greening. Practical use: Establishing withdrawal periods. Challenge: Detection limits in complex matrices.

Parthenocarpic fruit - related: Seedless, hormone imbalance fruit development without fertilization, sometimes induced by plant growth regulators that can interact with toxin pathways. Example: Gibberellin application leading to seedless grapes. Application: Studying toxin transport to fruit. Challenge: Altered metabolite profiles complicating toxicological assessments.

Pharmacokinetics - related: ADME, bioavailability the study of absorption, distribution, metabolism, and excretion of plant toxins in organisms. Example: Rapid hepatic metabolism of pyrrolizidine alkaloids in humans. Practical relevance: Dosing regimens for therapeutic plant extracts. Challenge: Inter-individual variability in metabolic enzymes.

Phytochemical screening - related: TLC, spectrophotometry preliminary tests to detect classes of compounds in plant extracts. Example: Dragendorff's reagent indicating alkaloids. Application: Guiding detailed analytical work. Challenge: False positives due to interfering substances.

Phytotoxicity assays - related: Seed germination, root elongation tests measuring the inhibitory effect of a substance on plant growth. Example: Lettuce seed germination inhibited by 50 % at 10 $\mathrm{mg\,L^{-1}}$ of herbicide X. Practical use: Evaluating environmental impact of industrial effluents. Challenge: Translating laboratory results to field conditions.

Phytoremediation - related: Phytoextraction, rhizofiltration the use of plants to remove, degrade, or stabilize contaminants, including toxic secondary metabolites. Example: Willow trees degrading phenolic pollutants

in wastewater. Application: Sustainable remediation. Challenge: Harvesting and disposal of contaminant-laden biomass.

Polymerase chain reaction (PCR) detection - related: Molecular diagnostics, pathogen monitoring amplification of DNA sequences to identify toxin-producing microbes on plants. Example: PCR for detecting *Fusarium* species that produce fumonisins. Practical relevance: Early warning systems for crop contamination. Challenge: Distinguishing viable from non-viable spores.

Polycyclic aromatic hydrocarbons (PAHs) - related: Combustion products, mutagenic organic compounds formed during incomplete combustion, which can be deposited on plant surfaces. Example: PAH accumulation on leafy vegetables near traffic. Application: Monitoring food safety. Challenge: Complex mixture analysis and source attribution.

Post-harvest handling - related: Storage, drying, detoxification procedures affecting toxin levels after crop removal. Example: Controlled drying reducing aflatoxin formation in peanuts. Practical use: Establishing standard operating procedures. Challenge: Balancing cost with efficacy.

Pre-emergence herbicide - related: Soil-active, seedling inhibition chemicals applied before weed seeds germinate. Example: Pendimethalin applied to cereal fields. Application: Integrated weed management. Challenge: Persistence leading to crop phytotoxicity under certain conditions.

Protein binding affinity - related: Docking, kinetics the strength of interaction between a toxin and a target protein, influencing potency. Example: High affinity of ricin B-chain for galactose residues. Practical relevance: Designing inhibitors. Challenge: In-vivo relevance may differ due to competition with endogenous ligands.