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ARTICLE

Toxic Plant Metabolites, Cyanogenic Glycosides, Poisoning Mechanisms, Health Risks, and Analytical Method Development for Detecting Toxicants in Food

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ABSTRACT

This study presents a novel robust titrimetric analysis method for detection and quantification of cyanide in food samples artificially spiked with cyanogenic compounds derived from bamboo and cassava species. The titration approach demonstrated a strong linear correlation between cyanide concentration and the volume of titrant required for complete neutralisation. Cyanogenic glycosides are naturally occurring plant toxins that can release hydrogen cyanide (HCN) upon enzymatic hydrolysis, posing a significant risk to human health. These compounds are found in various plants, including bitter almonds, cassava, and wild cherries, and play a defensive role against herbivorous. However, their presence in food sources raises concerns about accidental poisoning, neurotoxic syndromes like tropical ataxic neuropathy and Konzo disease, and potential long-term health effects. Food safety concerns, detoxification methods, and strategies to minimise cyanogenic risks through proper food processing and dietary awareness. Understanding these toxic secondary metabolites is crucial for ensuring food safety and preventing health hazards associated with plant-based diets and traditional herbal medicine practices. Results showed that increasing cyanide levels directly

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corresponded to higher titrant volumes, with 2 ppm cyanide requiring 22 mL of titrant and 25 ppm requiring 550 mL, confirming the method's reliability. Comparison with standard cyanide detection protocols validated the accuracy and consistency of the titrimetric technique. Reproducibility of results across different concentrations and sample types highlights the robustness and precision of this method, making it suitable for cyanide monitoring in various food matrices. This approach offers a practical, robust novel analytical-technique for routine food safety analysis, particularly in toxicological analysis.

Keywords: Accidental Poisoning; Chemical Warfare Agents; Food Contamination and Food Processing Safety; Herbal Medicine Toxicity; Hydrogen Cyanide (HCN); Cyanogenic Glycosides; Neurotoxic Syndromes–Tropical Ataxic Neuropathy

1. Introduction

1.1. Cyanogenic Glycosides: The Hidden Poison in Everyday Plants and How to Stay Safe

Cyanogenic glycosides are natural chemicals found in some plants, like cassava and bitter almonds. When these plants are chewed or damaged, the chemicals break down and release hydrogen cyanide (HCN), a dangerous poison. If too much is eaten or if the food is not prepared properly, it can lead to serious health problems, including dizziness, breathing difficulties, and even death in extreme cases. Eating small amounts over time can also cause nerve damage and disorders like tropical ataxic neuropathy and Konzo disease, which are common in areas where people rely heavily on these foods. Proper processing methods like soaking, cooking, and fermenting can help make these plants safer to eat [1,2].

Cyanogenic glycosides are the substances or compounds naturally occurring as plant secondary metabolites found in species such as cassava, bitter almonds, and bamboo. Upon tissue disruption through processes such as chewing, chopping, or crushing, these compounds were enzymatically hydrolysed, leading to the release of hydrogen cyanide (HCN), a well-recognised toxic agent. The liberation of HCN represented a significant defence mechanism in plants and posed potential health risks when cyanogenic plant materials were improperly processed or consumed.

Excessive consumption, improper or inadequate preparation of these foods was associated with acute toxicity, manifesting as dizziness, respiratory impairment, and, in severe cases, mortality. Prolonged low-level exposure was associated with neurotoxicity, leading to neurological disorders including tropical ataxic neuropathy and konzo disease [1,2].

Always soak, cook, or ferment these foods before eating them, and don't let a plant take you down [1–3].

It is essential to understand that poisonous plants seldom target just a single organ or system; rather, they often produce a wide range of effects throughout the affected animal's body. The degree of toxicity associated with a specific plant can fluctuate considerably, influenced by various environmental factors. As a result, a plant that is harmful under particular circumstances—such as periods of drought-induced stress—may pose little or no threat under more favourable conditions [4].

Some thorns of cactus, roses and other wild varieties of plant thus have toxic substances that can turn fatal, give nausea, stroke, hallucinations and neurotoxic syndromes including delusions. In some cases, exposure to these toxins can lead to life-threatening complications if not treated promptly.

Namely few of the conditions are discussed here: Anaphylaxis, Cardiotoxicity, Cytotoxicity, Delusions, Dermatitis, Hallucinations, Hypotension/Hypertension, Nausea, Neurotoxicity, Paralysis, Peripheral Neuropathy, Phytotoxicity, Respiratory Distress, Stroke (Cerebrovascular Accident—CVA), Toxin-induced Psychosis.

Concerns are growing as the issue of food fraud, which includes the more specific category of adulteration motivated by financial gain, is increasingly recognised in the food industry [5].

Numerous novel techniques for evaluating the safety and possible hazards of chemicals and toxic substances

have been developed as a result of advancements in toxicological research [6].

Apart from natural toxins, many deliberate toxins can contaminate food and poison human such as synthetic dyes, namely *Lawsonia inermis*, commonly called mendy locally; adulterated with similar dyes can be fatal to skin cells, and can cause cancer. Other body dyes that are harmful to humans, such as Silver nitrate, which, on exposure to sunlight, causes darkening and eliminates the skin cells to dye and, in many cases, can cause Argyria or argyrosis. Many street foods, particularly items like samosas and chutneys, are often enhanced with artificial dyes to create a more visually appealing appearance. For instance, an orange-coloured dye is frequently added to chutneys to make them look more vibrant and more colourful. However, certain dyes used in food can have long-term effects on the skin, particularly when exposed to sunlight. Individuals with lighter skin tones may notice their complexion turning a dull brown over time, resulting in an undesirable change. On top of that, some of these food colourants have been linked to premature greying of hair, affecting overall appearance. Unfortunately, such harmful practices often go unnoticed and unrecognised, and the presence of these contaminants in street food and market products does not contribute to a healthy lifestyle. Thus, many food materials at the market or in the streets are often contaminated and with such dyes that don't strengthen good life.

An experienceable intense pain might be felt, leading a subject to cry out in distress due to severe burns and itching caused by exposure to a particular ink that might contain concentrated silver nitrate. Such ink led to the formation of hollow, deep wounds with noticeable eschar on the fingers if they had been stuck using a pen, which might leave the person in pangs of pain for very long, often leading to loud weeping. The product lacked any usage instructions, and prolonged contact might result in significant damage to fingertips. Such injury caused excruciating nerve pain, leading to uncontrollable cries of agony due to severe chemical-induced skin corrosion. Such an incident usually remained unreported.

Silver nitrate is widely known for its toxic effects upon direct contact with the skin and mucous membranes, often leading to a condition called argyria. However, there is surprisingly limited data regarding its potentially harmful effects following ingestion. Only a handful of cases have been documented in medical literature, highlighting the rarity of such incidents.

Given this scarcity of information, a particular study aimed to investigate the consequences of ingesting silver nitrate [7]. In one notable case, a 15-year-old girl accidentally consumed a small amount of silver nitrate solution in liquid form. She experienced immediate adverse effects, but there was a lack of extensive reports detailing the impact of ingestion in medical literature. Interestingly, while previous cases of ingestion have occasionally resulted in severe complications, this particular case had a relatively mild outcome. The patient exhibited a temporary darkening of the skin and mucous membranes, especially in the throat and nasal regions, without any significant bleeding or tissue erosion. Endoscopic evaluations and follow-up assessments showed no lasting damage or long-term complications [7].

Although this case had a favourable resolution, it highlights the importance of understanding the toxicological effects of silver nitrate ingestion, given the limited data available. More research is needed to assess the potential risks associated with its accidental or intentional consumption, as well as to establish appropriate medical interventions for managing such cases [7].

Thus, silver nitrate ($AgNO_3$) can act as a toxic dye due to its strong oxidising properties and ability to react with organic matter, particularly proteins and skin [7,8].

Silver nitrate acts as a toxic dye due to:

- Staining effect
    1. Silver nitrate reacts with skin and tissues, forming silver salts (mainly silver chloride) that darken upon exposure to light, resulting in permanent brownish-black stains.
    2. This reaction is similar to early photographic processes [8].
- Toxicity
    1. Corrosive to tissues: Causes burns and irritation upon contact with skin and mucous membranes.
    2. Cytotoxic: Can damage living cells by disrupting proteins and DNA.

3. Argyria risk: Long-term exposure can cause argyria, a condition where silver particles accumulate in tissues, leading to irreversible bluish-grey skin discolouration.
4. Environmental toxicity: Harmful to aquatic life due to silver ion release [8].

- Historical & medical use
  1. Used as an antiseptic and cauterising agent in medicine.
  2. Previously used in staining tissues for microscopic examination.
  3. Applied in tattooing and marking (historically) due to its staining properties.

Silver nitrate is not a dye in the traditional sense, but it acts as a toxic staining agent due to its ability to bind with biological materials and darken over time. Its toxicity limits its use in many human applications [8].

1.2. Mechanism of Staining Effects

Upon contact with skin, silver nitrate reacts with chloride ions present in bodily fluids to form silver chloride. This compound undergoes photoreduction when exposed to light, resulting in a brownish or black discolouration of the skin. This staining is often transient but can be persistent depending on the extent of exposure [8].

1.3. Toxicity

Silver nitrate is corrosive and can cause tissue damage upon contact. Ingestion of silver nitrate can lead to severe gastrointestinal irritation, including nausea, vomiting, and diarrhoea. In one reported case, a 15-year-old female ingested 15 cc of silver nitrate solution, experiencing an excruciating burning sensation in her throat and nostrils, followed by vomiting. Fortunately, her clinical and endoscopic follow-up was benign, without signs of oesophageal damage [8].

Chronic exposure to silver compounds can lead to argyria, a condition characterised by a bluish-grey discolouration of the skin due to silver deposition. While primarily a cosmetic concern, it indicates significant silver accumulation in the body [8].

1.3.1. Silver Nitrate as a Toxic Dye and Its Role in Argyria

(1) Understanding Argyria and Silver Nitrate

Argyria is a rare dermatological condition characterised by a bluish-grey discolouration of the skin and mucous membranes due to the accumulation of silver particles in the body. This occurs when silver compounds, such as silver nitrate, interact with biological tissues and remain permanently embedded, progressively accumulating over time. The severity of discolouration often depends on the method and amount or concentration of silver exposure [8].

(2) Silver Nitrate as a Toxic Dye

Silver nitrate is a powerful oxidising agent that readily reacts with proteins and other organic compounds, causing irreversible staining when it comes into contact with the skin. The extent of this staining is influenced by the form in which silver is introduced to the body. When silver nitrate solution is applied topically, it reacts with chloride ions in the skin, leading to the formation of silver chloride. Upon exposure to light, this compound darkens and becomes embedded in tissues, resulting in persistent discolouration [8].

(3) Research Evidence on Silver Nitrate Deposition

A study investigating the staining effects of silver-based dressings on human skin utilised hydrofiber and silver nitrate-based dressings on biological samples. The results showed that when the dressings were hydrated with water, the silver nitrate-based dressing released approximately 30 times more silver particles into the tissue compared to a hydro fibre dressing ($p < 0.005$). However, when saline was used instead of water, the silver release was significantly lower for both dressings. This finding highlights the importance of the hydration medium in silver deposition and its potential toxicity [8].

While silver nitrate has been widely used for medical applications, including as an antiseptic and a cauterising agent, its potent oxidising nature makes it a toxic dye that can cause long-term skin discolouration (argyria). Once deposited, silver particles remain in tissues permanently, accumulating over time. Regulating its use and application method is essential to prevent unintended exposure and long-term toxicity [8].

Exposure to silver nitrate through certain soaps and food dyes can lead to noticeable changes in appearance. When consumed in small amounts, it might be present in street foods or market products, gradually affecting skin pigmentation and causing discolouration, which is often non-melanin and unnatural pigmentation, like a tattoo. Over time, this can lead to skin damage and may induce premature greying of the hair in the younger population and teens. The presence of silver nitrate in everyday items, even in minimal quantities, makes unregulated use a potential health concern.

Although several antidotes for silver toxicity have been proposed, there is no clinical evidence proving their necessity, as silver is quickly eliminated from the bloodstream. However, certain compounds have shown potential in counteracting its effects. Dimercaptosuccinic acid (DMSA) and glutathione have demonstrated the ability to bind with silver, facilitating its removal from the body [7,9,10].

Furthermore, in cases where methaemoglobinemia occurs, methylene blue has been effectively used to restore normal haemoglobin function [7,9,10].

Minimising aggravating variables, such as minimising sun exposure, wearing sun protection, and avoiding additional silver exposure, is a key management goal. D-penicillamine, hydroquinone, and dermabrasions have all been tried as potential therapies, but with little success [11,12].

(4) Types and Effects of Silver Exposure: Understanding Argyria

One of the most recognised complications of silver exposure is argyria, a condition that results in a persistent bluish-grey discolouration of the skin.

This condition is categorised into three primary subtypes: generalised argyria, localised argyria, and argyrosis.

Although considered a rare dermatological condition, once silver particles are deposited in the skin or ocular tissues, they become permanent and may continue to accumulate over time. While argyria is mainly a cosmetic concern, further research is necessary to understand its full implications and potential treatment options [13].

1. Generalised argyria develops when silver is absorbed systemically, leading to widespread skin discolouration, particularly in areas frequently exposed to sunlight. Early signs often include the appearance of a pale bluish tint on the skin, which may first be observed in the oral and buccal mucosa, later progressing to a deeper greyish-blue hue across the body [13].
2. Localised argyria, on the other hand, is restricted to specific areas of the skin or mucous membranes. This typically results from direct and prolonged exposure to silver-containing substances such as topical creams, medical solutions, or silver-based medical devices. The most commonly recognised form of localised argyria is the amalgam tattoo, which appears as a flat, dark-blue discolouration on the mucosa due to silver particle deposition [13].
3. The third variant, argyrosis, affects the eyes and occurs when silver deposits accumulate in the conjunctiva or cornea, leading to discolouration. These ocular silver deposits can cause the eyes to take on a greyish, bluish, or even brownish hue, particularly in areas such as the conjunctiva and cornea [13].

(5) Neurological Effects of Silver Exposure

Prolonged exposure to silver can lead to neurological complications due to its accumulation in neurons and glial cells within the brain and spinal cord. Studies on animal models suggest that silver salts may contribute to central nervous system dysfunction, as observed in mice. As well, on top of that, research on foetal rats has shown a reduction in emergent hippocampal pyramidal cells, indicating potential developmental neurotoxicity. In one documented case, a 55-year-old woman who self-administered silver-containing products for nine years to treat oral mycosis developed neurological impairments, including vertigo, muscle weakness, decreased sense of smell (hyposmia), difficulty walking (gait disturbance), and reduced skin sensation (cutaneous hypoesthesia). Examination revealed that prolonged silver exposure resulted in silver sulphide deposits accumulating in basal membranes, macrophages, connective tissues such as elastic and collagen fibres, the protective sheath (perineurium) surrounding peripheral nerves, and necrotic cells in the oral submucosa. These findings highlight the potential risks associated with chronic silver exposure, particularly its neurological impact, warranting further research into its long-term effects on the nervous system [12,14].

(6) Cardiovascular Effects of Silver Exposure

Chronic exposure to silver has been linked to potential cardiovascular complications. A case study by Steininger *et al.* reported the presence of silver deposits in the walls of multiple blood vessels during the autopsy of a 52-year-old patient who had succumbed to cardiac failure. This individual had been undergoing long-term treatment for a duodenal ulcer for over 18 years, during which they had consumed a total of 35 g of silver, leading to systemic silver accumulation [12].

Research conducted by Olcott as discussed in Steck and Murray (2025) on laboratory rats found that prolonged exposure to silver nitrate through drinking water resulted in left ventricular enlargement, a condition that can contribute to cardiovascular dysfunction. These findings suggest that long-term ingestion of silver compounds may have detrimental effects on the heart and vascular system, though further research is needed to establish the full scope of its cardiovascular impact [12].

(7) Other Conditions

Other conditions include haematologic, hepatic problems, renal, and respiratory [12].

1.3.2. Plant Poisoning: The Role of Toxic Secondary Metabolites in Plant Defence

Plants frequently cause poisoning due to the presence of specific chemical compounds. These toxic substances are typically secondary metabolites, meaning they are not essential for plant growth but serve other functions, primarily as a defence mechanism against herbivores and insects [15].

1.3.3. Classification of Toxic Plants: Effects, Compounds, and Taxonomic Groupings

Poisonous or toxic plants can be categorised through various approaches, with the most significant classifications based on the organs or systems they affect and the symptoms they produce. For instance,

1. Cardiotoxic plants include *Datura*, *Nerium*, *Digitalis*, *Asclepias*, *Atropa*, *Abrus*, *Adenium*, *Ephedra*, and *Convallaria majalis* [16].
2. Hepatotoxic species such as *Senecio*, *Crotalaria*, *Heliotropium*, *Echium*, *Nolina*, *Lupinus*, *Cycas*, *Agave*, and *Lantana* primarily affect the liver [16].
3. Neurotoxic plants include *Conium*, *Atropa*, *Datura*, *Lupinus*, *Aconitum*, *Hyoscyamus*, *Cestrum*, *Solanum*, *Veratrum*, *Astragalus*, *Oxytropis*, *Cycas*, *Bowenia*, *Nerium*, *Cassia*, and *Centaurea* [16].

Certain plants, like *Nicotiana*, *Solanum*, *Lupinus*, and *Astragalus*, are known for their teratogenic effects [16].

Plants may also be grouped according to the nature of their toxic compounds.

Examples include those containing glycosides—such as *Digitalis*, *Asclepias*, *Aloe*, *Convallaria*, *Aconitum*, and *Nerium*—and those producing cyanogenic compounds, like *Taxus*, *Prunus*, *Triglochin*, and *Sorghum* [16].

Others contain pyrrolizidine alkaloids, found in *Senecio*, *Amsinckia*, *Crotalaria*, *Heliotropium*, *Echium*, *Lantana*, and *Agave lechuguilla* [16].

Some plants, like *Amaranthus*, *Sorghum*, and *Chenopodium*, accumulate nitrates, while *Halogeton* is known for oxalate accumulation. Selenium-accumulating plants include *Gutierrezia* and *Pinus ponderosa*. Lastly, species like *Festuca*, *Glycyrrhiza*, *Medicago*, *Trifolium*, and *Cytisus* may exhibit oestrogenic activity [16].

As a further point, toxic plants can also be classified taxonomically by their botanical family and genus [16].

1.3.4. Human Exposure to Toxic Plants: Pathways, Risks, and Public Health Implications

Toxic plants can impact a wide range of organisms, from insects to humans [15,17]. In humans, their effects vary from isolated poisoning incidents to large-scale outbreaks, with outcomes ranging from mild discomfort to, in rare cases, fatal consequences. Human exposure occurs in several ways, including direct skin contact, intentional consumption, and accidental ingestion—either directly or through contaminated plant- or animal-based foods. Most cases of plant ingestion are intentional rather than accidental, as plants are often consumed for food, medicinal purposes, or psychoactive effects. In some instances, toxic plants are ingested in acts of self-harm or suicide [15].

A vast number of plant species synthesise toxins, either as a defence mechanism or for other biological purposes. When ingested, these toxic compounds can pose serious health risks to humans, leading to both personal harm and economic losses. Consumption of toxic plants may

occur accidentally, due to deliberate or unintentional contamination, or out of necessity when food supplies become scarce. While many poisoning incidents involve individuals—often young children—there have also been large-scale outbreaks affecting thousands of people. Advances in analytical techniques have enabled the identification and quantification of nearly all major plant-derived toxins [15].

Thus, cyanogenic glucosides, classified as phytoanticipins, are found in over 2500 plant species. They play a crucial role in plant defence, primarily by deterring herbivores with their bitter taste and their ability to release toxic hydrogen cyanide when plant tissues are damaged. However, recent studies suggest that these compounds serve additional functions beyond defence. They act as storage molecules for reduced nitrogen and sugars, which can be mobilised and utilised in primary metabolic processes when needed by the plant [18].

Cyanogenic plants possess hydrogen cyanide in a bound state, which is typically released when their tissues are crushed or damaged. These plants produce cyanogenic glycosides, where the hydroxyl groups of cyanohydrins (α-hydroxynitriles) derived from aldehydes or ketones are chemically bonded to a sugar, most commonly D-glucose. Extensive research has been conducted on the biosynthesis, distribution, and enzymatic breakdown of these compounds, particularly in seedlings of sorghum and flax [1,19].

Cyanogenic glycosides have the potential to release hydrocyanic acid (also known as prussic acid or cyanide). Structurally, these compounds are glycosides of 2-hydroxynitriles, which undergo enzymatic hydrolysis by β-glucosidase, leading to the formation of cyanohydrin. This intermediate is unstable and subsequently decomposes into hydrocyanic acid [1].

Notable cyanogenic glycosides include amygdalin, which is present in bitter almonds and peach kernels—both commonly used in traditional Chinese medicine—and prunasin, found in the bark of wild cherry (*Prunus serotina*). It is believed that the minute amounts of cyanide released from wild cherry bark contribute to its cough-suppressing effects, although this has not been definitively proven through modern pharmacological studies. Both amygdalin and prunasin break down into benzaldehyde during hydrolysis, giving wild cherry bark its distinct almond-like fragrance [1].

On top of that, linseeds (*Linum usitatissimum*, or flax) contain cyanogenic glycosides such as linustatin, neolinustatin, and trace amounts of linamarin [1].

Cyanogenesis is the process by which living things produce hydrogen cyanide (HCN) or prussic acid. Higher plants that display this phenomenon have one or more chemicals that, when hydrolysed, release HCN. Higher plants have two different kinds of cyanogenic substances: cyanogenic lipids and cyanogenic glycosides. When the sugar or corresponding fatty acid moiety is eliminated, both of these compounds, which are derivatives of α-hydroxynitriles (cyanohydrins), release a carbonyl molecule and HCN. Many qualitative tests that are fairly specific can identify the HCN that has been released in this way. The majority of cyanogenic plant reports in the literature are based on these assays [20]. In many traditional food serving cultures, it is a practice to serve food in bamboo cane baskets and bamboo utensils as an easy and the cheapest option available in the forest and tribal zones.

Mistaken identity is another common cause of poisoning. Certain toxic plants resemble edible species, leading to accidental consumption. For instance, mildly toxic flower bulbs like daffodils and tulips can be mistaken for onions, while the highly poisonous deadly nightshade bears a resemblance to edible berries like blueberries. Similarly, dangerous plants such as poison hemlock and hemlock water dropwort closely resemble wild carrots, parsnips, and chervil, increasing the risk of misidentification [15].

Pharmacognosy, derived from the Greek words *pharmacon* (medicine) and *gnosis* (knowledge), is the scientific study of the identification, characterisation, and phytochemical composition of natural drugs, primarily medicinal plants and their derivatives, thus become the excellent cause of study at such events and cases. Interestingly, the word "drug" originates from the Old French term *drogue*, which originally referred to dried herbs. Today, the scope of pharmacognosy has expanded beyond the traditional study of natural substances to include their pharmacological properties. While some use the term specifically to refer to herbal pharmacology, this interpretation is not entirely accurate within the broader scientific context [1].

The increasing popularity of natural herbal remedies has also led to cases of poisoning, often due to a lack of knowledge about a plant's toxic properties, misidentification, or unawareness of potential health risks. Regulatory

bodies in developed countries have implemented measures to address these concerns through licensing and safety regulations [2].

Likewise, some biological toxins share similar mechanisms of action with conventional chemical warfare agents. These agents are typically categorised into several groups based on their primary toxic effects: nerve agents that disrupt cholinesterase activity, vesicants that cause severe blistering and skin damage, pulmonary agents that target the respiratory system, and blood agents that interfere with oxygen transport. While this classification is based on their principal mode of toxicity, other characteristics—such as the speed of onset and early symptoms—can help identify the specific agent involved in a chemical attack. Recognising these signs quickly is essential for initiating emergency response measures, preventing further harm, and administering appropriate medical treatment [21].

Proper food preparation is crucial in some cases, as certain plant toxins require specific treatments to reduce their harmful effects. For example, lupin seeds need processing before consumption, and many raw beans must be thoroughly cooked to eliminate toxins [15].

Poisoning can also result from accidental overdoses, excessive consumption, or scepticism about a plant's toxicity. In some cases, toxins can enter the food chain, contaminating animal-derived products like milk, bird eggs, and honey when animals forage on toxic plants. Plant toxins may be found in various parts of the plant, including the roots, leaves, fruits, and seeds, and can be harmful when ingested or through skin exposure. Toxic plants may be consumed in their raw state or after processing methods like drying or cooking, which can sometimes reduce toxicity but may not always render them safe for consumption [15].

However, eating from bamboo, Cyanogenic glycosides (CGs) are secondary metabolites and natural products found in plants. These compounds consist of an α-hydroxynitrile aglycone attached to a sugar molecule, most commonly d-glucose. CGs are widely distributed across the plant kingdom, with at least 2500 known taxa containing these compounds. Many of these taxa belong to families such as: *Fabaceae, Rosaceae, Linaceae,* and *Compositae.* Various methods have been developed to quantify CGs, ranging from traditional indirect photometric techniques to modern direct chromatographic methods [22].

The genetic mechanisms controlling cyanogenesis are diverse, and plants exhibit significant variability in the amount of hydrogen cyanide (HCN) produced. This variation depends on both the biosynthesis of CGs and the presence or absence of enzymes that degrade these compounds. The biosynthesis of CGs begins with different l-amino acids, which undergo hydroxylation to form N-hydroxylamino acids. These intermediates are subsequently converted to aldoximes, which are transformed into nitriles, hydroxylated into α-hydroxynitriles, and finally glycosylated to produce CGs [22].

The hydrolysis of CGs to release HCN occurs in two steps: first, the glycosidic bond is cleaved by β-glucosidase, and then the resulting α-hydroxynitrile is broken down by α-hydroxynitrilase. In intact plant tissues, the separation of CGs and their hydrolytic enzymes within different cellular compartments prevents widespread hydrolysis and cyanide release [22].

The levels of CGs in plants are influenced by various developmental and ecological factors. These compounds play essential roles in physiological processes and act as defence mechanisms against herbivores and pathogens. The toxic effects of CGs, due to HCN release, have been observed in various animals, including cows, sheep, donkeys, horses, and poultry. Symptoms of poisoning vary but can include respiratory distress, neurological symptoms, and even death [22,23].

The toxicological impact of cassava (*Manihot esculenta*), particularly its roots, has been extensively studied in both experimental animals and humans. Improperly processed cassava, which contains high levels of CGs, can cause cyanide poisoning, highlighting the importance of appropriate preparation methods [22,23].

A vast number of plant species synthesise toxic compounds, either as a defence mechanism or for other biological functions. When ingested, these toxins can have harmful effects on humans, leading to health complications and financial consequences. Consumption of toxic plants may occur accidentally, through deliberate ingestion, contamination, or as a last resort when food supplies are scarce. While many poisoning incidents involve a single individual—often a child—there have also been large-scale outbreaks affecting thousands of people. Advances in

analytical techniques have enabled the identification and quantification of the key toxic components in most of the major poisonous plants [15].

Cyanogenic glycosides (CNglcs) are specialised bioactive compounds in plants that originate from amino acids. These molecules are structurally defined as α-hydroxynitriles (cyanohydrins) that remain stable due to glucosylation. Advances in analytical chemistry have significantly expanded the known diversity of CNglcs by detecting less prevalent variants modified through hydroxylation, glycosylation, and acylation. The process of cyanogenesis, where hydrogen cyanide is released from CN-glucosides, serves as a potent defence mechanism against generalist herbivorous but proves less effective against fungal infections. Over evolutionary time, CNglcs have taken on additional roles, contributing to plant adaptability by enhancing establishment, resilience, and survival under various environmental stresses. Their concentration tends to be higher in young plants, in nitrogen-rich conditions, or under suboptimal growth circumstances. Researchers are working on engineering CNglcs into certain crops to enhance pest resistance, while in other cases, efforts focus on eliminating them to ensure food safety. Since many staple crops naturally contain these compounds, understanding the molecular pathways governing cyanogenesis is essential for predicting how plants will respond to future environmental challenges [24].

When the tissues of Brassica plants are crushed or cooked, their glycosides undergo hydrolysis, leading to the release of volatile compounds such as isothiocyanates, nitriles, and thiocyanates. The primary toxic component, oxazolidine-2-thiones—particularly goitrin (5-vinyloxazolidine-2-thione)—interferes with thyroid function by binding iodine, thereby inhibiting thyroxine production and reducing its secretion from the thyroid gland [15].

Red kidney beans (*Phaseolus vulgaris*) and several other bean varieties contain the lectin phytohemagglutinin, which binds to oligosaccharides on red blood cell membranes. This disrupts protein transport across cell membranes, triggers mitosis, and causes red blood cells to clump together (agglutination), leading to symptoms such as nausea, vomiting, and diarrhoea. Also, phytohemagglutinin affects cellular permeability to proteins and transport mechanisms. Poisoning from red kidney beans is referred to as Kinkoti bean poisoning [15].

Although phytohemagglutinin is present in various beans, red kidney beans contain significantly higher levels—approximately three times more than white beans and ten times more than broad beans. The toxicity of beans is measured in hemagglutinating units (hau), with raw kidney beans containing between 20,000 and 70,000 hau. Proper cooking significantly reduces toxicity, lowering hemagglutinin activity to about 200–400 hau [15].

During the 1970s, there was significant interest in the potential use of a synthetic cyanogenic glycoside, patented as Laetrile (mandelonitrile β-glucosidase), as an alternative treatment for cancer. However, much of what was marketed under the name Laetrile was actually amygdalin, a naturally occurring cyanogenic glycoside with presumably similar effects when administered orally or via injection. The underlying hypothesis suggested that cancer cells contain β-glucosidase, which could activate circulating cyanogenic glycosides, making them selectively toxic to tumours. Yet, studies in both animals and humans demonstrated that amygdalin lacked effectiveness as an anticancer agent, likely due to the low β-glucosidase activity in cancer cells [1].

An innovative adaptation of this theory involved conjugating β-glucosidase to a tumour-specific antibody. When combined with amygdalin *in vitro*, this approach enhanced the cytotoxic effect of amygdalin on cancer cells by 36 times [1].

Chronic exposure to subacute levels of cyanogenic glycosides in daily diets has been linked to long-term toxic effects. Detoxification pathways in humans, such as the conversion of cyanide into rhodanide and cyanocobalamin, have been associated with severe conditions, particularly neurotoxic syndromes. This mechanism is believed to contribute to tropical ataxic neuropathy in Nigeria. In several African regions, the consumption of cassava (*Manihot esculenta*, also known as tapioca), in combination with a diet low in sulphur-containing amino acids, has been implicated in an endemic neurological disorder known as konzo, which affects upper motor neurones. The peeled cassava root contains significantly lower concentrations of cyanogenic glycosides. Outbreaks of konzo, particularly in Mozambique, are often linked to insufficient processing of cassava during periods of drought or conflict, which can

lead to higher exposure to toxic compounds [1].

Certain specialised herbivores, particularly insects, have adapted to feeding on cyanogenic plants. These organisms have evolved mechanisms to either metabolise cyanogenic glucosides or store them for their own defence against predators. Some arthropods, including certain millipedes, centipedes, and insects, possess the ability to synthesise cyanogenic glucosides de novo, while others acquire these compounds from their diet. This is notably observed in the larvae of *Zygaena* (family *Zygaenidae*). In *Zygaena filipendulae*, the concentration and composition of cyanogenic glucosides are precisely regulated, playing multiple roles beyond defence. These compounds are involved in key biological processes, including mating, where males transfer cyanogenic glucosides as a nuptial gift. Besides, hydrogen cyanide contributes to male attraction and nitrogen metabolism. As more plant and arthropod species are investigated, it is expected that cyanogenic glucosides will be found to be even more widespread and integral to various physiological and ecological functions [18].

Despite the long-standing tradition of incorporating bamboo shoots into tribal diets, their true potential as a nutritious food source has remained relatively underexplored. There is now a growing need to investigate their nutritional composition, medicinal properties, microbiological significance, and economic value from a comprehensive standpoint. Widely consumed in several Asian countries, bamboo shoots form an integral part of traditional cuisine and are gradually gaining popularity in Western regions as well. Characterised by low fat content, high dietary fibre, and rich mineral levels, they resemble an ideal vegetable and have been consumed by indigenous communities worldwide for generations. In recent times, increased interest from research groups across Asia has highlighted bamboo's remarkable nutritional and therapeutic potential, supported by its use in various traditional medicinal practices [25].

A comparative analysis of three bamboo species—*Bambusa vulgaris*, *Bambusa ventricosa*, and *Oxytenanthera abyssinica*—revealed the presence of saponins, general glycosides, coumarins, and cyanogenic glycosides across all species. In contrast, none of them exhibited the presence of alkaloids, carotenoids, triterpenoids, steroids, anthraquinones, or anthracene glycosides. Among the three, *Bambusa vulgaris* emerged as the most chemically safe, containing only four classes of phytochemicals [26].

Bamboo shoots are recognised for offering a wide range of health benefits, including antioxidant and free radical-scavenging properties, anti-ageing and anti-cancer potential, cardiovascular protection, support in weight management, digestive enhancement, blood pressure reduction, and antimicrobial effects. These health-promoting effects are primarily attributed to the presence of flavones and glycosides. In traditional Indo-Persian and Tibetan medicine, a substance called bamboo manna—derived from the *Bambusa arundinacea* species—is valued as a tonic for treating respiratory conditions. Also, the juice extracted from pressed bamboo shoots exhibits protease activity, which aids in protein digestion and has applications in cleaning wounds, treating maggot-infested sores, and healing ulcers, particularly when combined with palm jaggery [25].

However, recent research has focused on quantifying taxiphyllin in various plant species. For instance, a study analysed taxiphyllin content in the leaves of *Hydrangea macrophylla* var. *thunbergii*, a plant used in traditional medicine. The findings indicated that taxiphyllin levels varied based on leaf size, colour, part, growth period, and soil pH. Notably, processing methods significantly reduced taxiphyllin content, suggesting that cyanogenic glycosides may not be the primary cause of reported food poisoning incidents associated with this plant [27].

The primary extractive compounds identified in the shoots of *Dendrocalamus giganteus* and *D. hamiltonii* include taxiphyllin (1), L-asparagine, 4-hydroxybenzaldehyde, and β-sitosterol. A detailed analysis of the free amino acid content is provided, along with a study demonstrating that administering radiolabelled taxiphyllin- [2,3,7–9] to the inner leaves of bamboo shoots results in the formation of labelled asparagine [28].

Howard Bradbury, from the Australian National University, as discussed in Hunter et al., has designed a series of simple testing kits that allow individuals without specialised training to assess cyanide levels in various plant materials. These kits can be used to detect cyanide in cassava roots and derived products, as well as in other

cyanogenic plants such as sorghum leaves, bamboo shoots, and flaxseed meal. The method involves placing a small sample of the plant or product into a container, along with filter paper containing the necessary catalyst and a strip of picrate paper. The container is then left undisturbed at room temperature overnight. By the next morning, after the breakdown of cyanogenic compounds into toxic gas is complete, the resulting colour change on the picrate paper reveals the level of toxicity present in the sample [2].

2. Research Methodology

2.1. Natural Occurrence of Cyanogenic Glycosides (CNGs) and Associated Hydrogen Cyanide (HCN) Content in Various Plants

(1) Cassava (*Manihot esculenta*)—The roots of this plant contain the cyanogenic glycosides linamarin and lotaustralin, with hydrogen cyanide (HCN) levels ranging from 15 to 1000 mg/kg [29].

(2) Sorghum (*Sorghum vulgare*)—The young leaves carry dhurrin, contributing to HCN levels between 750 and 790 mg/kg [29].

(3) Flax (*Linum usitatissimum*)—The seed meal contains linamarin, linustatin, and neolinustatin, releasing 360–390 mg/kg of HCN [29].

(4) Lima bean (*Phaseolus lunatus*)—The beans are rich in linamarin, and the HCN content ranges from 2000 to 3000 mg/kg [29].

(5) Giant taro (*Alocasia macrorrhizos*)—Its leaves possess triglochinin, which results in 29–32 mg/kg of hydrogen cyanide [29].

(6) Bamboo (*Bambusa arundinacea*)—Young shoots of bamboo are known to contain taxiphyllin, releasing between 100 and 8000 mg/kg of HCN [29].

(7) Apple (*Malus species*)—The seeds are a source of amygdalin, with HCN content between 690 and 790 mg/kg [29].

(8) Peach (*Prunus persica*)—The kernels contain both amygdalin and prunasin, contributing to an HCN range of 785–813 mg/kg [29].

(9) Apricot (*Prunus armeniaca*)—Apricot kernels also carry amygdalin and prunasin, producing 696–764 mg/kg of HCN [29].

(10) Nectarine (*Prunus persica var. nucipersica*)—Kernels of this variety release between 196 and 209 mg/kg of HCN due to the presence of amygdalin and prunasin [29].

(11) Bitter almond (*Prunus dulcis*)—The kernels contain high levels of amygdalin and prunasin, resulting in approximately 4700 mg/kg of hydrogen cyanide [29].

Cyanide intake from cassava has been associated with thyroid dysfunction and the development of goitre. These health effects have not been commonly observed in populations with lower dietary exposure to cyanide, such as in developed countries. However, cases have been documented where children who consumed large amounts of apricot kernels, which naturally contain cyanogenic compounds, exhibited symptoms such as rapid breathing, low blood pressure, severe headaches, and even coma, with some cases resulting in death [2].

There is no direct evidence linking cyanide exposure to birth defects or reproductive disorders in humans. However, laboratory studies on animals have shown that cassava-based diets resulted in birth abnormalities in rats, while sodium cyanide exposure in drinking water led to reproductive system damage in rats and mice. Other cyanide-related effects observed in animal studies closely resemble those recorded in human cases [2].

2.2. Cyanogenic Glycosides

(1) **Chemical Structure:** They are glycosides (sugar-bound molecules) containing a cyanide group (–CN).

(2) **Common Examples:**

The chemical structures of representative cyanogenic glucosides are presented in **Figure 1**. Specifically, the molecular configurations of Amygdalin, Linamarin, Dhurrin, and Taxiphyllin are shown in **Figure 1a–d**, respectively, highlighting their potential to release hydrogen cyanide upon enzymatic hydrolysis.

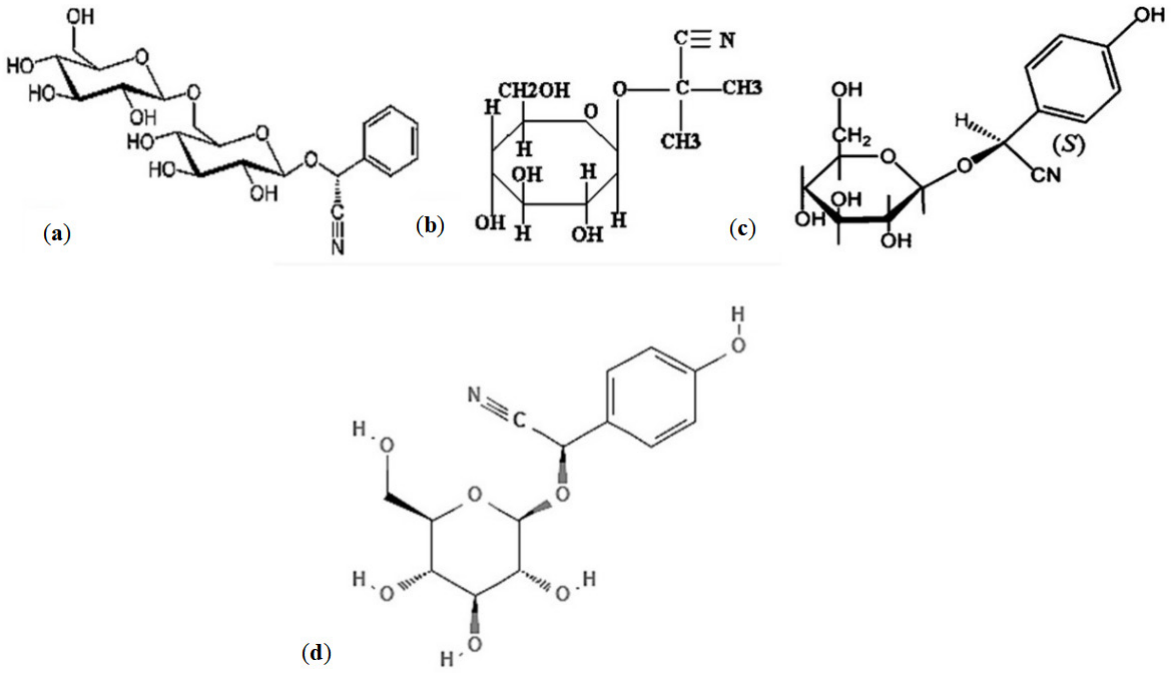

Figure 1. Chemical structures of key cyanogenic glucosides found in various plant sources: (**a**) Structure of Amygdalin (Found in Bitter Almonds, Apricot Kernels) [30]; (**b**) Linamarin (Cassava, Lima Beans) [9,31]; (**c**) Dhurrin (Sorghum). Cyanogenic Glucoside Dhurrin (*β*-D-glucopyranosyloxy-(S)-*p*-hydroxymandelonitrile) [32]; (**d**) Taxiphyllin (Bamboo Shoots) [33].

Bamboo shoots are known to contain cyanogenic glycosides, specifically taxiphyllin. While cyanide poisoning typically arises after consuming such glycoside-containing plants, cases resulting from inhaling hydrogen cyanide (HCN) gas—especially from pickled bamboo shoots—are extremely rare and previously undocumented [3].

This report highlights a case involving eight individuals who suffered acute cyanide poisoning after being exposed to HCN gas emitted from a well where bamboo shoots were being pickled. The affected individuals exhibited a rapid decline in consciousness and developed metabolic acidosis. Cyanide was detected in all of them. A simulation study further confirmed the release of HCN in the air within the well's environment [3].

This incident represents a rare occurrence of mass cyanide poisoning via inhalation, resulting in two deaths. Uniquely, the source of the toxic HCN gas was identified as fermented bamboo shoots undergoing the pickling process [3].

A total of eight individuals were exposed after a series of unsuccessful rescue attempts in a 27 m^3 well containing pickled bamboo shoots, following which all immediately lost consciousness. After retrieval, two individuals developed cardiac arrest accompanied by severe metabolic acidosis and subsequently died. Four others exhibited metabolic acidosis but recovered with supportive medical management. The remaining two individuals regained consciousness shortly after exposure and recovered without complications [3].

Environmental air analysis and measurement of cyanide levels in the bamboo shoots supported the diagnosis. All affected individuals demonstrated high anion gap metabolic acidosis with preserved oxygenation. Blood cyanide concentrations, measured approximately 18 h after exposure, ranged from 2.66 to 3.30 μg/mL. Ambient air sampling conducted 21 h after the incident showed an oxygen concentration of 20.9% and sulfur dioxide levels of 19.4 ppm; however, hydrogen cyanide (HCN) could not be directly detected due to instrumental limitations. A subsequent simulation study identified the presence of HCN and sulfur dioxide in the well atmosphere at concentrations of 10 ppm and 7.5 ppm, respectively. Analysis of the pickled bamboo shoots revealed cyanide concentrations ranging from 39 to 434 mg/kg in wet samples [3].

Affected individuals experienced an abrupt onset of altered consciousness and metabolic acidosis following exposure, with cyanide exposure confirmed in all cases. The

simulation study further substantiated the presence of hydrogen cyanide in the confined environment containing the bamboo shoots [3].

Thus, this case series documented an episode of mass acute cyanide poisoning resulting in two fatalities. The source of hydrogen cyanide was atypical, originating from the pickling process of bamboo shoots within a confined space. The findings highlighted the potential for significant cyanide generation from fermented plant products and brought attention to the risks associated with confined-space exposure [3].

The visibility of flowers to pollinators can be influenced by their colour, which is dependent on the visual perception of visiting species. This aligns with the role of floral colour in attracting specific pollinators and signalling deterrence to herbivores through traits like unpalatability. Supporting this idea, research shows that red-flowered species within the *Hakea* genus tend to produce more cyanogenic compounds compared to their white-flowered counterparts. Similarly, wild radish (*Raphanus sativus*) flowers that are pink or bronze exhibit elevated glucosinolate levels when compared to white or yellow ones. In the case of Madagascar periwinkle (*Catharanthus roseus*), deeper hues like dark pink and purple were associated with higher alkaloid concentrations than those found in lighter-coloured varieties such as pink and white [34].

The diversity and ornamental potential of cultivated and hybrid *Hakeas* are illustrated in **Figure 2**. Specifically, notable species and garden selections are catalogued in **Figure 2**, while unique morphological traits, such as foliage forms and floral structures—from needlewoods to cauliflower blooms—are highlighted in **Figure 2**.

Figure 2. Cultivated and Hybrid *Hakeas*: A Botanical Catalogue of Notable Species and Garden Selections, from Needlewoods to Cauliflower Blooms: A Curated Collection of *Hakea* Species and Hybrids. (**a–b**) *Hakea bucculenta*; (**c**) *Hakea laurina x petiolaris* 'Pin Ball'; (**d**) *Hakea archaeoides*; (**e–f**) *Hakea macreana—Willow Needlewood*; (**g**) *Hakea pachyphylla*; (**h**) *Hakea purpurea* [35,36].

Other *Hakea* noted:

1. *Hakea archaeoides*,
2. *Hakea* 'Burrendong Beauty',
3. *Hakea bakeriana*,
4. *Hakea cinerea*—Ashy Hakea, *Hakea clavata*, *Hakea coriacea*—Pink Spike Hakea,
5. *Hakea corymbosa—Cauliflower Hakea*, *Hakea cucullata*—Cup *Hakea*, *Hakea elliptica*,
6. *Hakea epiglottis*, *Hakea eriantha*—Tree Hakea, *Hakea francisciana* 'Pomonal Pink',
7. *Hakea gibbosa—Hairy Hakea*, *Hakea invaginata*, *Hakea laurina* 'Stockdale Sensation',
8. *Hakea macreana*—Willow Needlewood [35,36].

2.3. Taxiphyllin Content in Bamboo Species: A Comparative Analysis of Cyanogenic Potential

Bamboo plants, like some other plants, have different amounts of cyanogenic glycosides—substances that can produce harmful hydrogen cyanide (HCN) when broken down in the body. One such compound found in bamboo is taxiphyllin. Among different bamboo varieties, *Dendrocalamus latiflorus* (Ma bamboo) exhibits the highest concentration of taxiphyllin, with 1058 mg/100 g in the initial harvest and 830 mg/100 g at peak harvest. Other species like *Dendrocalamus giganteus* (Launong) and *Bambusa edulis* also show considerable levels, although lower than Ma bamboo. Meanwhile, species such as *Phyllostachys makinoi* and *Phyllostachys pubescens* have unreported or negligible data regarding taxiphyllin content (**Table 1**) [2]. **Table 1** presents data on various bamboo species and the corresponding levels of Taxiphyllin present in each, providing a comparative overview of their cyanogenic potential.

When comparing cyanide levels across a broader range of plant materials, data reveal that certain parts of plants, such as cassava leaves and the tops of bamboo sprouts (e.g., *Bambusa vulgaris*), can contain extremely high concentrations, reaching up to 800 mg HCN/100g. Young leaves of sorghum and flax seedling tops also exhibit significant cyanogenic potential (**Table 2**) [2]. On a qualitative scale adapted from Gibson (1984), cassava ranks highest (++++) in cyanide content, followed by members of the *Prunus* genus (e.g., apricots, cherries, bitter almonds) and lima beans (+++). Sorghum, linseed, millet, and bamboo shoots fall into a moderate risk category (++), while sweet potatoes and maize are categorised as low risk (+) due to their minimal cyanide content (**Table 3**) [2]. These findings emphasise the importance of proper preparation and processing, especially for plants with high cyanogenic potential, to reduce health risks associated with cyanide exposure. Thorough cooking and fermentation methods are commonly employed to lower toxicity levels, particularly in bamboo shoots, cassava, and certain legumes.

Table 1. Different Bamboo Species Data Representation on Taxiphyllin Content Present in It [2].

Common Name	Scientific Name Given	Taxiphyllin (mg/100 g)	
		Initial Harvest	Peak Harvest
Ma bamboo	*Dendrocalamus latiflours* Munro	1058	830
Launong	*Dendrocalamus giganteus*	690	378
Edible bamboo	*Bambusa edulis* (Odash) Keng	786	556
Green bamboo	*Bambusa oldhamii* Munro	700	410
Makino	*Phyllostachys makinoi* Hayata	-	-
Moso (any season)	*Phyllostachys pubescens* Mazel ex Houz Lehaie	-	-
Usawa Cane	*Pseudosasa usawai* Hay	-	-

Table 2. Cyanide in Various Plant Materials [2].

Plant	Part	mg HCN/1000 g Fresh Weight mg HCN/kg Fresh Weight
Cassava	Leaves	770–1040
	Bark of Tuber	690–840
	Inner part of tuber	70–330

Table 2. *Cont.*

Plant	Part	mg HCN/1000 g Fresh Weight mg HCN/kg Fresh Weight
Lima Bean	America white seed	100
	Java Coloured seed	3120
	Puerto Rico seed	4000
Sorghum	Fruits	6
	Etiolated tips of Shoots	2400
	Young green leaves	600
Bamboo (*Bambusa vulgaris)*	Unripe stem	3000
	Top of sprout	8000
Flax	Linseed	210–540
	Seedling tops	9100
Bitter Almond	Seed	2900
	Young leaves	200
Apricot	Seed	400–4000
Cherry	Seed	1000
Cherry Laurel	Leaves	1500

Table 3. Plant (Level of Relative Cyanide).

Entry	Plant/Plant Group	Qualitative Cyanogenic Level
a.	Cassava contains the highest relative levels of cyanide, making it one of the most cyanogenic food plants.	(++++)
b.	Various species of the Prunus genus, including apricots, cherries, and almonds, have significantly high cyanide content.	(+++)
c.	Certain varieties of lima beans also contain elevated cyanide levels, posing potential toxicity concerns if not properly processed.	(+++)
d.	Sorghum is another plant with moderate cyanide concentrations, especially in its leaves and young shoots.	(++)
e.	Linseed (flaxseed) contains a moderate amount of cyanogenic glycosides, which can release cyanide upon metabolism.	(++)
f.	Millet, a widely consumed grain, has a comparable cyanide content to sorghum and linseed.	(++)
g.	Bamboo shoots also contain moderate levels of cyanide, which necessitates thorough cooking to ensure safety.	(++)
h.	Sweet potatoes have relatively low cyanide content compared to other cyanogenic plants but can still contribute to exposure.	(+)
i.	Maize (corn) contains the lowest levels of cyanide among these plants, posing minimal risk under normal dietary consumption.	(+)

Source: Adapted from the work of Gibson (1984), as discussed in Hunter et al. [2].

Table 2 provides a comparative overview of cyanide content (measured as mg HCN per 100 g fresh weight) found in various plant materials, including cassava, lima beans, sorghum, bamboo, flax, and several fruit seeds and leaves, highlighting the varying levels of cyanogenic potential across different plant species and tissues.

Table 3 summarises the relative levels of cyanide content in various plant species, ranging from high to low, using a qualitative scale (++++) to (+). The data, adapted from Gibson (1984), highlight cassava and certain *Prunus* species as having the highest cyanogenic potential, while maize and sweet potatoes show minimal levels.

2.4. Utilisation and Growth of Bamboo in Culinary and Domestic Contexts

Bamboo is not only a vital ecological resource but also deeply integrated into culinary and domestic practices, particularly in many Asian cultures. Its applications span from food preparation and serving to sustainable

household utility items. The use of bamboo in the culinary context is both traditional and environmentally friendly. For instance, bamboo sticks are used as spoons for serving vegetable rice (**Figure 3a,d**), offering a biodegradable alternative to plastic cutlery. Cooked bamboo shoots (**Figure 3b**) and fried bamboo shoots (**Figure 3c**) are popular dishes, valued for their nutritional content and unique flavour, often served as side dishes or main courses.

Figure 3. Utilisation and Growth of Bamboo in Culinary and Domestic Contexts. (**a**) Vegetable rice served with a bamboo stick spoon. (**b**) Cooked bamboo shoot vegetable dish. (**c**) Fried bamboo shoots prepared as a side dish. (**d**) Vegetable rice served with bamboo utensils for an eco-friendly presentation. (**e**) Polished bamboo stick used as an eco-friendly alternative for serving ice cream or vegetable skewers. (**f**) Bamboo stick used for frying vegetables in traditional cooking. (**g**) Bamboo stick designed for serving or holding ice cream. (**h**) Bamboo basket used for storing wheat-based flatbreads such as Indian roti or chapati. (**i**) Traditional bamboo basket for keeping wheat bread/Indian flatbreads warm. (**j**) Wooden bowl served with noodles and accompanied by a bamboo stick. (**k**) Handcrafted bamboo vessels for household or decorative use. (**l**) Bamboo plant growing in arid, desert-like sandy soil, showcasing its resilience. (**m**) Another view of bamboo thriving in hot desert sand conditions. (**n**) Bamboo plant cultivated in a household earthen pot for domestic or ornamental use. (**o**) Collection of bamboo-crafted vessels reflecting sustainable and traditional craftsmanship.

Polished bamboo sticks (**Figure 3e**) serve multiple purposes in modern and traditional kitchens. They are used not only for grilling or frying vegetables (**Figure 3f**) but also for holding ice cream (**Figure 3g**), providing a sustainable substitute for disposable sticks made of plastic or wood. This eco-conscious approach extends to the use of bamboo in food storage and presentation. Bamboo baskets (**Figure 3h,i**) are traditionally employed to store wheat-based Indian flatbreads such as roti or chapati, keeping them warm and fresh while adding a rustic charm to mealtime presentation.

Beyond the kitchen, bamboo continues to play an important role in domestic settings. For instance, a wooden bowl accompanied by a bamboo stick is commonly used for serving noodles (**Figure 3j**), combining natural materials for a harmonious dining experience. Handcrafted bamboo vessels (**Figure 3k**,**o**) exemplify traditional craftsmanship and are used for both functional and decorative purposes around the home.

In terms of cultivation, bamboo's resilience is remarkable. It thrives even in arid, sandy desert soils (**Figure 3l,m**), illustrating its adaptability and strength as a sustainable plant. Additionally, bamboo can be grown in household earthen pots (**Figure 3n**), making it a practical and aesthetically pleasing plant for domestic and ornamental use.

Together, these uses highlight bamboo's versatility, sustainability, and cultural relevance. Whether in culinary applications, household utilities, or ornamental gardening, bamboo stands out as an eco-friendly resource that supports both traditional lifestyles and modern sustainability goals (**Figure 3**).

2.5. Live Herbarium of Bamboo: Collection, Preparation, and Importance in Botanical Study

Bamboo, a fast-growing and highly versatile grass, holds significant ecological, economic, and cultural value. Preserving bamboo as a live herbarium specimen provides a practical and sustainable approach to studying its morphological diversity and growth patterns. Unlike traditional dried herbarium specimens, live herbarium models allow for real-time observation of leaf arrangement, culm structure, node and internode variations, and other physiological traits.

The collection process begins with selecting healthy, representative bamboo specimens from various habitats—ranging from arid regions to household pots. Once collected, the plants are carefully transplanted into containers or garden beds that simulate their natural environment. Proper care is essential to maintain their health and ensure they remain viable for long-term observation.

Preparation for live herbarium display includes labelling each specimen with botanical information such as scientific name, collection site, and date. The use of eco-friendly containers and supportive structures helps maintain upright growth while allowing for accessible viewing. This method not only enhances learning and teaching in botanical sciences but also supports conservation awareness by showcasing living biodiversity in educational settings.

Overall, live herbarium collections of bamboo serve as dynamic, interactive tools for plant taxonomy, ecological research, and sustainable education.

The morphological features and growth habit of bamboo are documented in **Figure 4**, which presents a photographic representation of bamboo maintained as a live herbarium specimen for botanical study and educational reference (**Figure 4**).

The morphological characteristics of *Manihot esculenta* are illustrated in **Figure 5**. Specifically, the tuberous roots, shown in **Figure 5a**, serve as the main edible component and a major carbohydrate source. **Figure 5b** displays the seeds, which are utilised for propagation and breeding research and are known to contain hydrogen cyanide (HCN). **Figure 5c** highlights the nutrient-rich leaves, which contribute to photosynthesis and plant development, and also contain potential levels of HCN in them.

Figure 4. Photographic representation of bamboo preserved as a live herbarium specimen for botanical study and educational reference.

Figure 5. Morphological features of *Manihot esculenta* (cassava) plant parts: (**a**) Tuberous roots, which serve as the primary edible portion and majour carbohydrate source; (**b**) Seeds, used for propagation and breeding studies contains levels of HCN; and (**c**) Leaves, which are rich in nutrients and play a role in photosynthesis and plant growth also contains potential levels of HCN.

Certain food sources can serve as carriers of cyanogenic compounds, which may be intentionally or artificially introduced as toxins. These substances have the potential to cause fatal consequences when unknowingly consumed. In some cases, cyanogenic compounds have also been found in food that targets large groups of people, such as those attending public food services, wedding celebrations, or free meal distributions. This might be deliberate accidental contamination poses a serious threat to health and safety, often going undetected until symptoms of poisoning, including severe distress and fatal reactions, manifest [37,38].

The oral toxicity threshold for cyanide ranges between 30 and 210 mg per kg of body weight. Notably, daily cassava flour intake tends to be higher in rural populations compared to urban ones, averaging 19.1 g and 4.7 g per person, respectively. In a study evaluating various Brazilian cassava-based food products, cyanogenic glycoside levels were quantified using a spectrophotometric method with absorbance measured at 530 nm. Cyanide concentrations were determined through enzymatic hydrolysis using linamarase. The measured cyanide content in 500 g samples was as follows: artisan toasted cassava flour contained 15 mg, sweet cassava starch had 32.5 mg, artisan dried cassava flour contained 37.5 mg, "bijuzada" cassava flour had 60 mg, industrially processed toasted cassava flour had 115 mg, industrial raw cassava flour reached 140 mg, and wet cassava flour exhibited the highest level at 225 mg. Regular consumption of these products with elevated cyanide levels could pose serious long-term public health concerns [39].

The following values represent the cyanide content per gram in various types of cassava flour and starch, along with their corresponding standard deviations, measured over 500 g of each product:

(1) Artisan toasted cassava flour showed a cyanide concentration of 15 mg/500 g, with a standard deviation of 0.0643.

(2) Sweet cassava starch, categorised based on its acidity into sweet or sour, exhibited a cyanide level of 32.5 mg/500 g, with a standard deviation of 0.1414 [39].

(3) Artisanal dried cassava flour contained 37.5 mg of cyanide per 500 g, with a deviation of 0.2242 [39].

(4) "Bijuzada" cassava flour, a specific type of processed product, had 60 mg of cyanide per 500 g, with a variation of 0.3606 [39].

(5) Industrialised toasted cassava flour recorded 115 mg of cyanide in 500 g, with a standard deviation of 0.3512 [39].

(6) Industrialised raw cassava flour contained 140 mg/500 g of cyanide, with a deviation of 0.4575 [39].

(7) Wet cassava flour exhibited the highest cyanide concentration at 225 mg/500 g, accompanied by a standard deviation of 0.6506 [39].

2.6. Sustainable Bamboo Cooking: A Traditional Method for Efficient and Eco-Friendly Food Preparation

Ensuring food safety is essential, especially when analysing potential food toxins. Many tourists who venture into remote areas or embark on jungle treks frequently report experiencing digestive discomfort, severe stomach cramps, or breathing difficulties after consuming locally prepared meals. These traditional cooking practices, often utilised in rural settings, involve unconventional methods such as boiling tea in coconut shells or serving hot beverages like coffee or tea in tender or matured bamboo or wooden cups.

One notable traditional cooking technique is bamboo cooking, particularly for preparing rice. This involves filling a thick, hollow bamboo stalk with rice, vegetables, and water, then sealing it and placing it in a fire chamber. However, instead of direct exposure to flames, the bamboo is positioned in a chute, where it is heated by circulating hot air rather than direct combustion. This method allows for efficient, controlled cooking, ensuring the food is evenly prepared while preserving its natural flavours.

Bamboo cookers are advantageous because multiple units can be positioned simultaneously in the chute, maximising fuel efficiency. Meanwhile, other food items can be cooked directly over the flames, optimising resource use. This cost-effective and sustainable approach makes bamboo cooking an intelligent solution for forest-based eateries, reducing fuel consumption while maintaining traditional culinary practices.

Despite some drawbacks, bamboo cooking remains a highly efficient, eco-friendly, and cost-effective method for traditional and outdoor cooking. With proper handling,

it can be a sustainable alternative for forest-based eateries and eco-tourism destinations, promoting responsible resource use while preserving the authenticity of indigenous culinary practices.

However, these traditional cooking methods can pose significant health risks, especially in cases of bamboo poisoning. For individuals who are not tolerant or resistant to certain natural toxins present in bamboo, consumption could lead to severe adverse effects. In extreme cases, such incidents may result in life-threatening consequences, making it crucial to ensure proper safety measures when using bamboo for food preparation.

Certain bamboo shoot preparations, such as pickles, can be toxic, though many people consume them without any noticeable adverse effects. However, bamboo as a food choice remains unappealing to some, either due to personal preference or the potential health risks it poses. Macroscopically, bamboo has a thick, rough texture, while its young shoots are more tender and edible. Despite this, they are not entirely risk-free and may not be the most suitable food option. Various precautions are taken to make bamboo pickles safer for consumption, yet simple and inherently safe foods are often a more reliable choice compared to those that require extensive processing to mitigate potential dangers.

Bamboo Spice, typically called 'Bamboo masala' in local or regional contexts, can cause severe threats, such as bamboo poisoning that leads to severe vomiting that can just overturn the entire intestine and make you faint due to difficulty breathing and may cause your natural death.

This is just the cyanogenic glycosides, poisoning sometimes safe, sometimes fatal, and life-threatening too, depending on the amount consumed and its concentration to bind with body proteins.

Other uncommon and less recognised bamboo preparations, such as preparation of Susundi, which is a type of fermented bamboo shoot preparation that is known for its strong aroma and distinctive taste.

The primary ingredient is fermented bamboo shoots, which are known to contain cyanogenic glycosides. Proper fermentation helps reduce toxicity. The bamboo shoots are chopped and fermented in airtight containers for several days or even weeks. Once fermented, they are mixed with mustard seeds, garlic, green chilies, salt, and mustard oil to enhance the flavour. Some variations include additional spices and even vegetables, depending on the regional preferences. Susundi has a strong, pungent flavour that might not appeal to everyone. It is considered a delicacy among many tribal communities, but it must be prepared carefully to avoid bamboo poisoning. Proper fermentation and cooking methods help in detoxifying the harmful compounds present in raw bamboo shoots.

Some of its notable benefits include fermented foods like Susundi, which are packed with probiotics that support digestion. Besides, they provide essential nutrients and antioxidants that contribute to gut health.

Sungu Sungu is a traditional drink made by mixing coconut water with fermented bamboo shoot extracts, creating a unique and flavourful beverage. It is an unrecognised food and drink classified as fraudulent food, bioweaponised food—intentionally laced with toxins for mass harm, often mixed with tadd juice or tadd sap and fermented Neera preparations, which is significantly unrecognised, often found with palm nectar too.

However, their preparation methods are neither well-documented nor widely acknowledged. Though relatively obscure, these foods are still consumed by certain groups. If you are uncertain but willing to try, there are cautions to proceed with. It is believed that women from certain communities discreetly mix this substance into men's food at night as a precautionary measure to deter possible attacks while they sleep. However, there is no substantial documented evidence to confirm the existence of such practices; moreover, there is no concrete or well-documented evidence to support this claim—it largely remains a matter of folklore and speculation.

Regardless of its perceived safety, the toxicity of bamboo-based and cassava-derived foods can lead to severe hallucinations and, in extreme cases, coma. Symptoms may appear immediately after consumption or develop gradually over two to three days. In affected individuals, this toxicity often triggers intense vomiting, severe stomach pain, intestinal blockage, and difficulty in passing food waste from the anus, leading to significant gastrointestinal distress.

The food-affected individual may experience extreme weakness, profuse sweating, and may eventually slip

into a dream-like state before succumbing to the effects of prolonged cyanide exposure. This occurs when bamboo, certain types of wood, or coconut shells with bamboo crafted spoon come into direct contact with food, leading to the gradual ingestion of toxic compounds.

Certain grasses, when used in cooking for flavour enhancement, may be easily digestible for some individuals while causing digestive discomfort for others.

The names Susundi and Sungu Sungu will often revolt your brain if you haven't heard them before and will stop your hunger there itself; if it doesn't, you are ready to consume your sickness cups.

From the chimney's chute to the bamboo's cooker, food cooking often involves a process that supports and has its instances.

Figure 6 depicts the collection and laboratory preparation of cyanogenic plant materials for toxin content analysis. Specifically, it illustrates the experimental setup using: scale-marked glassware for soaking whole bamboo segments (**Figure 6a**), a double-neck flat-bottom flask used to grow and assess the toxicity of different bamboo varieties (**Figure 6b**), and measurable glassware employed for soaking diced bamboo samples under controlled laboratory conditions (**Figure 6c**).

Figure 6. Collection of Cyanogenic Plant Materials for Toxin Content Analysis. Laboratory equipment used in the experimental preparation and analysis of bamboo samples: (**a**) Measurable scale glassware employed for soaking whole bamboo segments; (**b**) Double-neck flat-bottom flask utilised for cultivating various bamboo varieties and assessing their toxicity levels; (**c**) Measurable scale glassware used for soaking diced bamboo pieces in controlled laboratory conditions.

Note: Sampled materials: Bamboo cyanogenic glycosides, *Manihot* plant leaves, *Colocasia gigantea* (Giant Colocasia/Elephant Ear), *Dieffenbachia seguine* (dumbcane), and *Dieffenbachia* sp. (leopard lily/tuftroot; *Araceae* family arums). Materials processed for analytical testing of cyanogenic compounds.

2.7. Conversion of Bamboo Cyanide Toxin to Detectable Potassium Ferrocyanide

Bamboo contains cyanogenic glycosides, such as taxiphyllin, which release hydrogen cyanide (HCN) upon enzymatic hydrolysis [2].

The process of converting this cyanide toxin into potassium ferrocyanide ($K_4[Fe(CN)_6]$) involves multiple steps:

- Step 1: Extraction of cyanide from bamboo

  1. Crushing & soaking
     - Fresh bamboo shoots are crushed or finely chopped.
     - They are soaked in water to allow enzymatic hydrolysis of cyanogenic glycosides into HCN.
     - The reaction is facilitated by β-glucosidase enzymes present in bamboo.

  2. Acidic hydrolysis (optional for higher yield)

If natural hydrolysis is slow, mild acid (like dilute sulfuric acid) can be added to accelerate cyanide release.

  3. Distillation & collection of HCN
     - The hydrolysed solution is gently heated in a distillation setup.
     - HCN gas is released and needs to be carefully absorbed into an alkaline solution to prevent toxicity.

- Step 2: Conversion of HCN to sodium or potassium cyanide

Absorption in alkaline medium

The collected HCN gas is bubbled into a solution of potassium hydroxide (KOH) or sodium hydroxide (NaOH), forming potassium cyanide (KCN) or sodium cyanide (NaCN):

$HCN + KOH \rightarrow KCN + H_2O$

This step must be done in a controlled fume hood due to extreme toxicity.

- Step 3: Formation of potassium ferrocyanide
  1. Reaction with ferrous sulphate
     - The prepared potassium cyanide (KCN) solution is reacted with ferrous sulphate ($FeSO_4$) in an aqueous medium: $6\,KCN + FeSO_4 \rightarrow K_4[Fe(CN)_6] + K_2SO_4$
     - This reaction forms soluble potassium ferrocyanide in solution.
  2. Purification and crystallisation

The solution is slowly evaporated to induce crystallisation of potassium ferrocyanide trihydrate ($K_4[Fe(CN)_6]\cdot 3H_2O$).

2.8. Analysis of Isolated Complex Cyanide in Pure State

The analysis procedure was performed using titrimetric analysis by observing colour change at the end point, which is detected as the end point of the presence of cyanide in the free state or in the complex state.

For these serial dilutions of 1 ppm to 25 ppm of the obtained cyanide, the titrating medium was prepared, and at the lowest dilution of the titrating medium, was conducted to give end point. This was done to evaluate the sensitivity of the results produced and check with the accuracy.

All the serial dilutions were performed in the normal drinking water; it was additionally assessed in the river and pond water to check the trueness of the process.

The titrant was laboratory prepared, and the complex was obtained as the poisoning material in the lowest poison form. The complex was obtained from ordinary material that will be mostly obtained from generalised chemicals, often available, such as caustic soda.

The titration was performed to check if the readings given are appropriately measurable in triplicate.

2.9. Analysis of Isolated Complex Cyanide in the Food and Juices and an *In Vitro* Analysis

The isolated cyanide complex was slowly admixed in small quantities, often known, churned manually in the water, citric acid, and slowly 400 mL of water was added and warmed at 37 ˚C for about 15 min. Then this was titrated with the titrating medium to check for the endpoint detection as shown in the following figures, which present a graphical representation of the measured cyanide levels in food samples.

Indicator: self-indicating, Titrating medium: 1 PPM $FeSO_4$.

$FeSO_4$ (Fe^{2+}) reduces cyanide complex species or reacts in redox-sensitive systems to form stable complexes like ferrocyanide: $6CN^- + Fe^{2+} \rightarrow [Fe(CN)_6]^{4-}$

This complex can subsequently be analysed through further titration or evaluated using colourimetric techniques.

2.10. Design and Working Principle of the ToxiGuard Cyanide Detection Device

2.10.1. Device Construction

The ToxiGuard device is engineered as a compact, dual-compartment system for rapid and precise cyanide detection in food and beverage samples. It consists of the following components (**Figure 7**):

1. Lower compartment (Titrant reservoir): A sealed, transparent chamber pre-filled with a standardised titrant solution. This compartment features a calibrated dispensing mechanism that releases a fixed volume (1 mL per drop) upon activation.
2. Upper compartment (Sample chamber): A graduated chamber designed to hold the test sample. The chamber is equipped with a secure, rotatable lid that ensures containment and controlled interaction with the titrant.
3. Aerosol pump mechanism: A precisely engineered dispensing system that allows controlled titrant release from the lower compartment into the upper

chamber. Each actuation delivers a uniform drop, ensuring accurate titration.

4. Graduated scale & observation window: The device features a visible measurement scale on both compartments, allowing real-time monitoring of titrant consumption and reaction progress.

ToxiGuard: The future of cyanide detection.

Protect lives, ensure safety!

i. **Ultra-precise cyanide detection -** Instant results with high accuracy.

ii. Easy to use - No expert training required.

iii. Versatile applications - Food safety, water analysis, and forensic testing.

iv. Reliable and certified - Shall be of great trusted in future use by professionals worldwide.

Figure 7. Illustrates the ToxiGuard device, a compact and user-friendly system engineered for efficient titration and toxicity analysis of diverse food and beverage samples, enabling easy use by both professionals and non-qualified individuals alike.

The design and functional components of the ToxiGuard device are illustrated in **Figure 7**. The system includes a lower titrant reservoir, an upper sample chamber, an aerosol pump mechanism for controlled titrant release, and a graduated scale with an observation window for real-time monitoring, enabling accurate and efficient cyanide detection in food and beverage samples.

The ToxiGuard device was thoughtfully designed and developed in the laboratory to enable easy and accurate titration of juices, foods, and other samples, including liquor, wine, TaddNira, and Nira-jaggery. Its user-friendly design ensures that even non-experts and household users can conveniently assess the toxicity levels of various food and beverage items, promoting safer consumption (**Figure 7**).

2.10.2. Working Principle

1. **Sample introduction**: The suspected food or liquid sample is placed into the upper compartment, and the lid is securely closed.
2. **Titrant dispensing**: The user activates the aerosol pump, releasing the titrant in controlled 1 mL increments into the sample chamber.
3. **Reaction observation**: The titrant interacts with potential cyanide compounds present in the sample, triggering a colorimetric reaction. The colour change provides a qualitative and semi-quantitative assessment of cyanide presence.
4. **Titrant level monitoring**: The transparent lower compartment allows users to track titrant usage, ensuring precise measurements and refilling when necessary.
5. **Refilling mechanism**: The titrant reservoir can be replenished at designated refill stations, ensuring continuous usability in field applications.

2.10.3. Applications and Significance

(1) On-site food safety testing: Ideal for express hotels, street food vendors, and tea stalls where food authenticity is often questioned.

(2) Emergency detection at public venues: Enables rapid testing in suspected poisoning cases.

(3) Regulatory and quality control: Facilitates routine inspections in food industries and public health sectors.

(4) Portability & ease of use: Designed for both trained professionals and non-specialists, ensuring widespread applicability.

3. Result and Discussion

3.1. Comparative Analysis of Cyanide and Taxiphyllin: Chemical Properties, Toxicity Mechanisms, and Analytical Detection

Cyanide and taxiphyllin, though both associated with toxicity, differ significantly in their chemical nature, source, and behaviour in biological systems. Cyanide is a potent inorganic poison, commonly found in both synthetic and natural environments, and acts directly by inhibiting cellular respiration through binding to cytochrome oxidase enzymes. In contrast, taxiphyllin is an organic cyanogenic glycoside predominantly found in certain plants, especially bamboo shoots. Taxiphyllin itself is not directly toxic; however, it becomes harmful only when it undergoes enzymatic breakdown, which leads to the release of free cyanide. This indirect toxicity mechanism makes taxiphyllin less immediately dangerous than cyanide under most conditions. A key distinction lies in their stability. Cyanide is relatively stable and retains its toxic potential unless chemically neutralised. Taxiphyllin, on the other hand, is heat-labile and breaks down during boiling or cooking, significantly reducing its toxicity. This makes proper food preparation crucial when consuming bamboo shoots or other cyanogenic plants. In terms of detection and quantification, cyanide can be accurately measured using volumetric redox titration methods. As shown in table for the volumetric determination of cyanide, it outlines a standard calibration where 1 mL of titrant corresponds to approximately 1 mg of CN^-, allowing for straightforward determination of cyanide concentrations in various samples. The use of argentometric titration—where silver cyanide (AgCN) forms—further supports the method's versatility and effectiveness. As illustrated in following figure showing the standard calibration curve, the calibration curve plotting cyanide concentration against titrant volume demonstrates strong linearity and precision, making it a reliable approach for analysing cyanide presence, whether from environmental exposure or food sources. Overall, understanding the comparative features of cyanide and taxiphyllin is vital not only for toxicological risk assessment but also for guiding safe consumption practices and accurate analytical detection.

3.2. Titrimetric Assessment of Cyanide in Food: Demonstrating Linearity, Sensitivity, and Reliability in *In Vitro* Analysis

The data presented in the following tables illustrate a clear and consistent linear relationship between the concentration of cyanide added to a food matrix, such as rice, and the corresponding volume of titrant required for its neutralisation during *in vitro* analysis. As the cyanide concentration increases from 2 ppm to 25 ppm, the volume of titrant needed rises proportionally—from 22 mL to 528 mL. This strong linear correlation demonstrates the reliability and sensitivity of the titrimetric method used for cyanide detection. Each incremental increase of 1 ppm in cyanide concentration corresponds to an approximate increase of 22 mL in titrant volume, confirming the method's accuracy in quantifying cyanide content in food samples. Such a consistent volumetric response indicates that the titration technique is not only effective but also well-suited for monitoring cyanide contamination in controlled food environments. This is especially important in food safety testing, where precise detection of even low levels of cyanide is critical for preventing potential health risks.

Thus, the rule for estimating cyanide concentration in food samples (via titration) can be noted as:

For every 1 ppm of cyanide present in the food matrix (e.g., rice), approximately 22 mL of titrant is required for complete neutralisation.

3.3. Procedure for Cyanide Quantification in Food Samples Using Titration

Application Steps:

1. Perform titration on the food sample until the endpoint (complete neutralisation of cyanide) is reached.
2. Record the total volume of titrant used (in mL).
3. Calculate the cyanide concentration (ppm) using the formula:

$$\text{Cyanide concentration (ppm)} = \frac{\textit{Volume of titrant used}\ (\text{mL})}{22}$$

This rule can serve as a quick and practical guideline for estimating cyanide levels in food safety testing using the described titrimetric method.

So, if 198 mL of titrant is used to neutralise a sample:

$$\text{Cyanide concentration (ppm)} = \frac{198\ (\text{mL})}{22} = 9\ \text{ppm}$$

3.4. Validation of Titrimetric Method Accuracy and Reproducibility in Cyanide Analysis of Food Samples

The data in the following tables show a perfect correlation between the experimental and standard titrant volumes across all tested cyanide concentrations, ranging from 2 ppm to 25 ppm. For each concentration level, the volume of titrant required for neutralisation in experimental trials exactly matches the standard reference values (e.g., 220 mL for 10 ppm, 330 mL for 15 ppm, etc.). This one-to-one correspondence confirms both the accuracy and reproducibility of the titrimetric method used for cyanide detection. Such consistency demonstrates that the method reliably produces precise results across multiple tests and is unaffected by variability in sample handling or analytical conditions. The linear relationship maintained throughout the concentration range further validates the method's robustness, making it suitable for routine cyanide analysis in food matrices. This high level of agreement between experimental and standard values reinforces the method's credibility for food safety monitoring and regulatory compliance.

3.5. Innovative Titration Method for Cyanide Detection in Non-Edible Plant-Derived Food and Household Items: Enhancing Public Health Safety

The titration-based method outlined presents a significant advancement in the detection of cyanide, particularly in non-edible plant species that are sometimes misused as food or come into contact with food and water sources. The widespread use of cyanogenic plants like bamboo, cassava, and certain millets—especially in areas with limited food security—poses a serious health risk when these materials are improperly processed or consumed. This risk extends beyond ingestion, as items such as bamboo utensils, drinking straws, and even musical instruments made from lower-grade bamboo can leach cyanide or its precursors, especially taxiphyllin, upon contact with moisture or human saliva. Notably, the inclusion of bamboo in non-food applications, such as water transportation (pipes) or traditional instruments like flutes, may inadvertently expose users to trace cyanide compounds. This is particularly concerning for children or amateur users, who may not recognise potential symptoms of low-level cyanide exposure, such as dizziness, nausea, or irritation. The titration method's accuracy, reproducibility, and simplicity make it highly suitable for screening both food products and household items derived from potentially hazardous plant materials. Its scalability and cost-effectiveness further enhance its applicability in low-resource settings where cyanogenic plants are commonly found and used. Implementing this method in routine quality checks can significantly reduce health risks, ensuring that both food and non-food materials meet acceptable safety standards. This novel application extends the importance of cyanide detection beyond traditional food safety into broader public health protection, highlighting the need for awareness and regulation in the use of plant-based materials in everyday life.

3.6. ToxiGuard Device: A User-Friendly, Semi-Quantitative Tool for Rapid Cyanide Detection in Food and Beverages

The ToxiGuard device represents a novel and practical advancement in the field of food safety and toxicological screening, offering a user-friendly, semi-quantitative method for detecting cyanide in food and beverage samples. Its operation is based on the integration of controlled titrant release and colorimetric detection, a combination that allows for accurate, visual assessment of cyanide concentration without the need for advanced instrumentation or technical training. This makes it particularly valuable for low-resource or field settings where rapid decisions regarding food safety must be made.

3.7. Innovative Dual-Chamber Design of ToxiGuard Enhances Precision, Usability, and Accessibility for Cyanide Detection

The dual-chamber design—with a sample compartment and a standardised titrant reservoir—ensures precise chemical interaction and minimises human error during testing. The real-time colorimetric output simplifies interpretation, and the transparent, graduated chambers further

enhance its usability by enabling visible titrant tracking. These features not only increase the device's accessibility to non-specialists but also make it suitable for **mass-market deployment** in both consumer and institutional settings.

3.8. Wide-Ranging Applicability and Patentable Innovations of the ToxiGuard Cyanide Detection Device

In terms of applicability, ToxiGuard is versatile. From roadside food vendors and emergency response teams to government inspectors and home users, the device can play a crucial role in early detection and prevention of cyanide exposure. The ability to use it in *on-site* testing scenarios—especially in regions where cyanogenic foods like bamboo shoots or cassava are consumed—provides a frontline defence against accidental or intentional poisoning. Its portability, reusability, and durable construction also align with sustainability goals, making it a long-term solution for routine safety monitoring.

From an intellectual property (IP) perspective, the ToxiGuard apparatus and its method of operation present several elements that are patentable. These include:

1. The dual-compartment titration chamber design with transparent graduated scales.
2. The aerosol-based titrant delivery system for incremental precision release.
3. The real-time colorimetric detection mechanism is directly linked to toxic compound concentration.
4. The modular and refillable architecture allows for repeated, sustainable use.

Patent and Copyright Protection for the Innovative Features of the ToxiGuard Device

Such innovations could be covered under both utility patents (for the functional aspects of the titration and detection system) and design patents (for the visual and ergonomic layout of the device). Not only that, all illustrations, schematics, and technical descriptions of the ToxiGuard included in the research are subject to copyright protection, ensuring the original authors retain exclusive rights to the creative and descriptive elements presented.

3.9. ToxiGuard: Bridging Public Health Needs with Commercial Potential and Future Expansion in Toxicological Diagnostics

As such, the ToxiGuard device not only fulfils a pressing public health need but also embodies significant potential for commercialisation and intellectual property protection. Future development and refinement of the device may also lead to broader applications, including the detection of other hazardous substances, positioning it as a foundational tool in portable toxicological diagnostics.

3.10. Key Differences

Comparative features of Cyanide and Taxiphyllin are highlighted, including their type, occurrence, toxicity, stability, and mechanism of action. While cyanide is a directly toxic inorganic compound, Taxiphyllin is an organic cyanogenic glycoside that becomes toxic only upon enzymatic breakdown, with its toxicity significantly reduced through heat treatment (**Table 4**).

Table 4. Comparison of Cyanide and Taxiphyllin: Chemical Nature, Toxicity, and Stability Characteristics.

Feature	Cyanide	Taxiphyllin
Type	Inorganic poison.	Organic cyanogenic glycoside.
Occurrence	Found in synthetic and natural sources.	Found in plants, especially bamboo shoots.
Toxicity	Directly toxic.	Indirectly toxic via enzymatic breakdown.
Stability	Stable under normal conditions.	Heat-labile; destroyed by boiling.
Mechanism	Inhibits cellular respiration directly.	Releases cyanide upon hydrolysis.

Table 5 shows the volumetric determination of cyanide using redox titration, with the method calibrated such that 1 mL of titrant corresponds to approximately 1 mg of CN^-. The data also support the applicability of argentometric titration through the formation of AgCN, highlighting the method's flexibility for cyanide quantification.

Figure 8 illustrates the standard calibration curve obtained by plotting known cyanide concentrations (ppm)

against the volume of titrant used for complete neutralisation. This curve provides a reliable reference for quantifying unknown cyanide levels in samples, demonstrating the method's sensitivity, linearity, and accuracy in titrimetric cyanide analysis.

Table 6 presents the *in vitro* measurement of cyanide concentrations in food materials, such as rice, spiked with known amounts of cyanide, demonstrating the method's effectiveness in detecting and quantifying cyanide levels in controlled food matrices.

Table 5. Volumetric Cyanide Determination with redox titration (Also Argentometric Titration Applicable as AgCN formation) (1 mL titrant ≈ 1 mg CN− Equivalent).

Cyanide Concentration (ppm)	Volume of Titrant (mL)
2	22
5	110
10	220
15	330
20	440
25	550

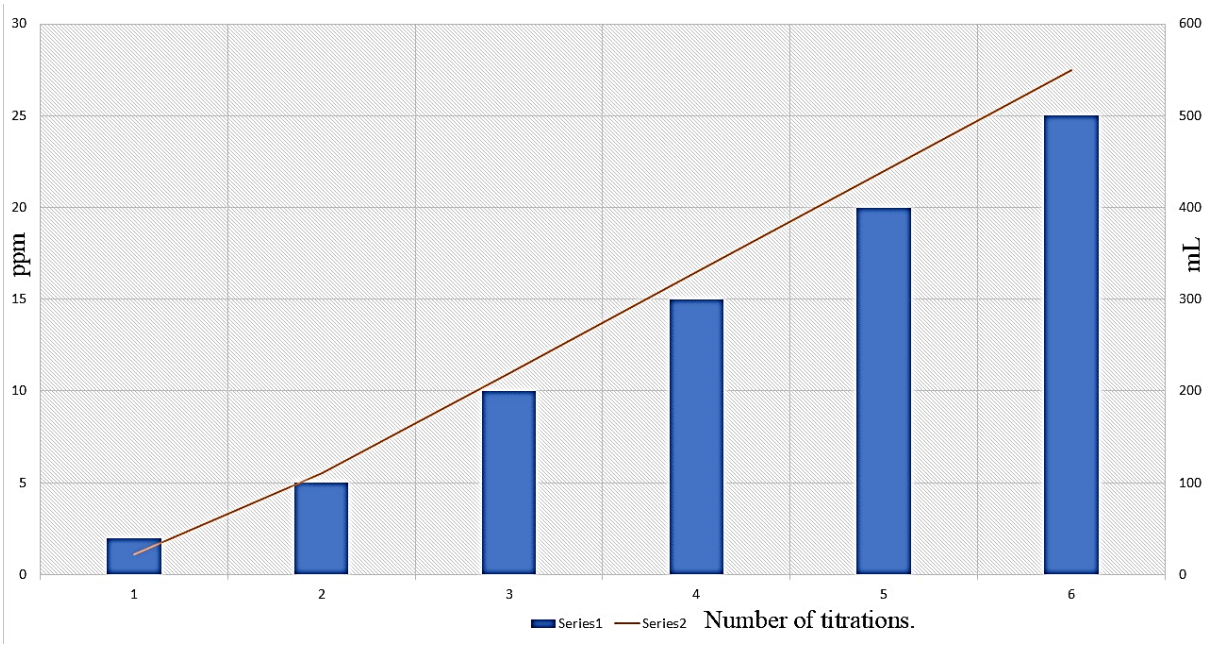

Figure 8. A graph of the standard calibration curve was generated by plotting known concentrations of cyanide (in ppm) against the corresponding volumes of titrant required for complete reaction.

Note: This calibration curve serves as a reference to determine unknown cyanide concentrations in test samples, enabling accurate quantification based on the linear relationship between cyanide levels and titrant volume. The curve validates the sensitivity, linearity, and reliability of the titrimetric method for cyanide analysis in various matrices.

Table 6. Measurement of Cyanide Concentration Added in Food Material Such as Rice, to Analyse Its Concentration (*In Vitro* Analysis).

Cyanide Concentration (ppm)	Volume of Titrant (mL)
2 ppm	22 mL
3 ppm	44 mL
4 ppm	66 mL
5 ppm	88 mL
6 ppm	110 mL
7 ppm	132 mL
8 ppm	154 mL

Table 6. *Cont.*

Cyanide Concentration (ppm)	Volume of Titrant (mL)
9 ppm	176 mL
10 ppm	198 mL
11 ppm	220 mL
12 ppm	242 mL
13 ppm	264 mL
14 ppm	286 mL
15 ppm	308 mL
16 ppm	330 mL
17 ppm	352 mL
18 ppm	374 mL
19 ppm	396 mL
20 ppm	418 mL
21 ppm	440 mL
22 ppm	462 mL
23 ppm	484 mL
24 ppm	506 mL
25 ppm	528 mL

Figure 9 illustrates the measured cyanide concentrations in food samples intentionally spiked with cyanide complexes derived from cassava and bamboo species, highlighting the effectiveness of the titrimetric method in detecting and quantifying cyanide levels across different matrices.

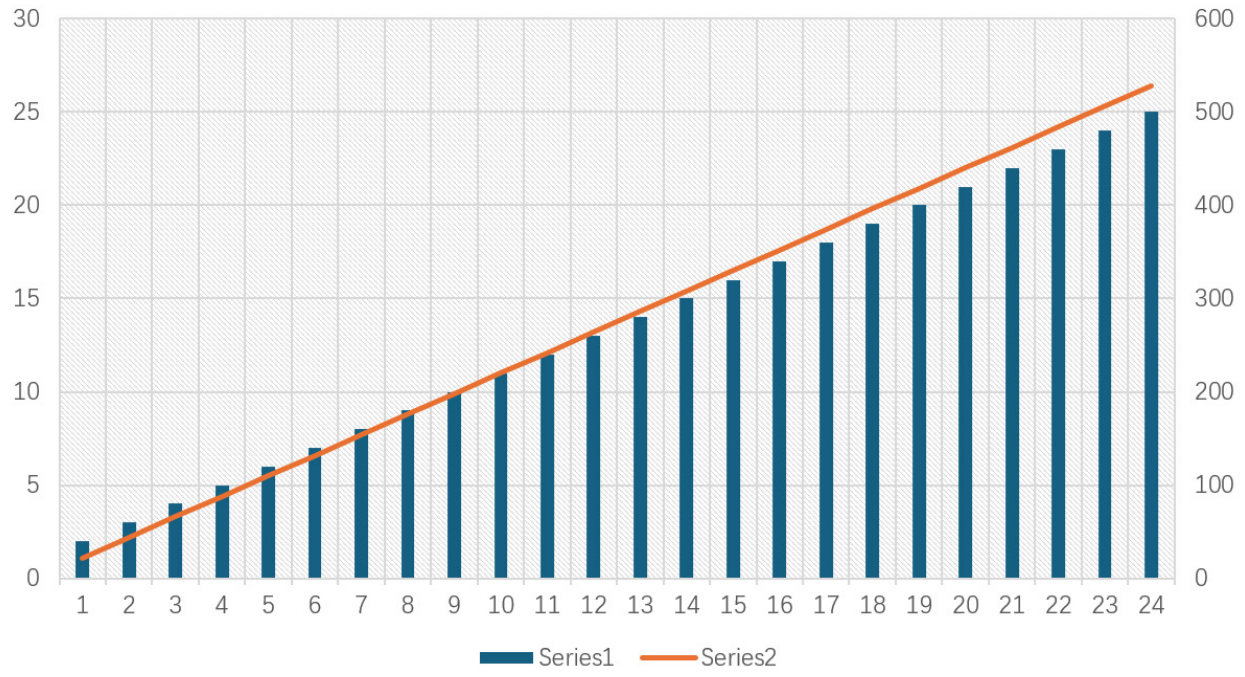

Figure 9. A graphic representation of the measured cyanide levels in food samples that were purposefully tainted with cyanide complexes obtained from cassava or bamboo plant species.

3.11. Detection of Cyanide Using Titrimetric Analysis

The titration method applied for cyanide detection in food samples spiked with cyanide complexes from bamboo and cassava species revealed a strong correlation between cyanide concentration and the volume of titrant required for neutralisation. The results obtained were compared with standard cyanide detection readings, demonstrating high accuracy and reliability. The volume of titrant increased linearly with cyanide concentration, indicating the robustness of this method for quantifying cyanide in various matrices.

The observed values align with the expected titration pattern, where a cyanide concentration of 2 ppm required 22 mL of titrant, and a concentration of 25 ppm required 550 mL. This consistency across multiple readings reinforces the precision of the titration method for determining cyanide presence in food and related substances.

3.12. Comparative Analysis with Standard Readings

When compared with standardised titration values, the experimental data showed a perfect correlation, confirming the method's reliability. Standard readings at specific intervals (2 ppm, 5 ppm, 10 ppm, 15 ppm, 20 ppm, and 25 ppm) matched exactly with the corresponding measured volumes, indicating that the titration process was executed with precision and free from systematic errors (**Table 7**).

Table 7. Comparison of Experimental and Standard Titrant Volumes for Cyanide Concentration, Demonstrating Accuracy and Reproducibility of the Titrimetric Method in Food Sample Analysis.

Cyanide Concentration (ppm)	Volume of Titrant (mL)—Experimental	Volume of Titrant (mL)—Standard
2 ppm	22 mL	22 mL
5 ppm	110 mL	110 mL
10 ppm	220 mL	220 mL
15 ppm	330 mL	330 mL
20 ppm	440 mL	440 mL
25 ppm	550 mL	550 mL

Table 7 presents a comparative analysis between experimental and standard titration volumes for various cyanide concentrations, demonstrating the accuracy, reproducibility, and reliability of the titrimetric method used for cyanide determination in food samples.

The near-identical readings indicate that the titrimetric method provides robust, reproducible, and accurate measurements for cyanide determination in various food matrices.

3.13. Novel Application in Cyanide Detection for Non-Edible Species Processed as Food or Used in Food and Water Supply

The method presented offers an efficient and novel approach to detecting cyanide in non-edible plant species that are sometimes improperly processed as food. Many plant species, such as bamboo shoots, cassava, and certain millet varieties, naturally contain cyanogenic glycosides, which can be converted into toxic cyanide compounds when improperly processed. Similarly, certain food utensils or water supplies may also be contaminated with trace amounts of cyanide from organic sources, such as bamboo utensils, bamboo pipes, and bamboo straws, which have taxiphyllin present in large quantities. When non-adult flute players play the instrument intimately over their lips, such presences can likewise have an unpleasant effect, if the flute isn't made of quality instruments.

This titration-based method provides a reliable means to monitor and assess cyanide contamination in food and water sources, ensuring that materials processed for consumption adhere to safety regulations. Given the ease of execution and high accuracy, this technique serves as an ideal candidate for large-scale cyanide monitoring, particularly in regions where cyanogenic plants are commonly consumed.

3.14. Principle and Applicability of the ToxiGuard Device

The ToxiGuard device operates on the principle of **controlled titrant release and colourimetric detection** for the rapid identification and semi-quantitative measurement of cyanide compounds in food and beverage samples. The device features a dual-chamber design, where the upper compartment holds the sample and the lower compartment contains a standardised titrant solution. Upon activation of the aerosol pump, precise volumes of titrant are incrementally dispensed into the sample chamber. The titrant reacts chemically with any cyanogenic compounds present, producing a visible colour change that correlates with cyanide concentration. This real-time colorimetric reaction provides users with a straightforward means to detect toxicity levels without requiring complex instrumentation or technical expertise. The transparent compartments and graduated scales enable accurate monitoring of titrant usage, enhancing measurement precision and ease of use.

3.15. Applicability

The ToxiGuard device is engineered for broad utility across diverse analyses:

1. **On-Site Food Safety Testing:** It allows express hotels, street food vendors, and tea stalls to quickly verify food authenticity and safety, helping prevent cyanide poisoning from contaminated ingredients.
2. **Emergency Detection:** The device facilitates rapid cyanide screening at public venues or suspected poisoning cases, enabling timely intervention.
3. **Regulatory and Quality Control:** Food industry inspectors and public health officials can utilise the device for routine monitoring and enforcement of safety standards.
4. **Portability and User-Friendliness:** Designed for use by both trained personnel and non-specialists, the device supports widespread application, including in household environments, due to its compact form and simple operation.
5. **Sustainability:** With refillable titrant reservoirs and durable construction, ToxiGuard supports repeated use in field and laboratory settings, promoting ongoing vigilance against food toxicity hazards.

4. Conclusions

The titration method utilised for cyanide detection in food and related substances has demonstrated exceptional accuracy and reliability. The obtained results give standard cyanide detection values, confirming the robustness of this approach. This method's ability to detect cyanide in processed non-edible species, food sources, water supplies, and utensils makes it a valuable tool for ensuring food safety and preventing cyanide-related toxicity.

As well, the simplicity of this method allows for widespread application, even in settings where advanced analytical instruments are unavailable; the test can be performed at the site of the event. It provides a cost-effective and scalable solution for both laboratory and field testing, enabling quick decision-making regarding food safety. The method is particularly beneficial in developing regions where cyanogenic plants are widely consumed, and the risk of cyanide exposure remains high.

Over and beyond that, this titration approach can be integrated into regulatory monitoring frameworks, supporting analysts and organisations in implementing stringent safety standards. It can also be adapted for use in industrial food processing, water treatment, and quality assurance protocols. The ability to detect and quantify cyanide and taxiphyllin with high precision and reproducibility makes this technique a crucial tool for mitigating health risks associated with cyanogenic food sources.

This titration-based cyanide, taxiphyllin detection method is not only accurate, reliable, and easy to implement, but also holds significant potential for safeguarding public health by preventing accidental cyanide poisoning through food, water, and utensil contamination. Future research could explore enhancements to this method, such as automation or the integration of spectrophotometric detection, to further improve sensitivity and efficiency in diverse analytical settings. Also, can be detected using the colourimetric method. Titration-based cyanide and taxiphyllin detection is now possible without a complex titration and can be easily performed by using the ToxiGuard device that was developed in this research. With sensitivity at 2 ppm, LOD. Detection at a concentration of 1 ppm is highly sensitive and typically requires photometric techniques; however, with careful and precise observation, it can be accurately assessed. Bamboo pickle, while widely popular and known for its high nutritional value according to several studies, poses

potential health risks if not properly processed. To ensure its safety for consumption, it is crucial to carry out a quantitative analysis of cyanogenic compounds. Therefore, this research is directed towards developing a scientifically validated method that offers a robust approach for both processing and detecting these toxic substances. "The procedure demonstrates high precision and is capable of detecting even at very sensitive levels."

The ToxiGuard device is an innovative, user-friendly tool developed for the rapid detection of cyanide in food and beverage samples through a controlled titration and colourimetric analysis system. Designed with a dual-compartment architecture, the device enables precise titrant delivery from a lower reservoir into an upper sample chamber via an aerosol pump. Upon interaction with cyanogenic compounds, a visible colour change occurs, providing a semi-quantitative indication of cyanide presence. This process eliminates the need for sophisticated laboratory instruments, making the device suitable for both professional and non-specialist users. ToxiGuard is applicable across a wide range of settings, including on-site food safety testing in street food stalls, emergency toxicity screening at public events, and routine inspections by regulatory bodies. Its compact size, refillable titrant system, and transparent measurement scales enhance usability, portability, and sustainability. By offering a practical and accessible approach to cyanide detection, the ToxiGuard device supports improved food safety practices and public health protection in both urban and rural environments.

The ToxiGuard device functions based on a newly developed and innovative analytical procedure specifically designed for the detection of cyanide using a redox titration approach. This method leverages the principles of redox chemistry, where cyanide ions undergo a measurable chemical reaction with a standardised titrant, resulting in a detectable change—typically observed through colourimetric indicators. The device incorporates this technique into a compact, user-friendly format, enabling accurate and efficient analysis of cyanide levels in various food and beverage samples. Its design supports both laboratory and field use, allowing for real-time monitoring and assessment of cyanide contamination, even by non-specialist users. This advancement enhances food safety testing by offering a reliable, accessible, and scientifically grounded solution for identifying toxic cyanide compounds in complex sample matrices.

Public Disclosure of a Patentable Matter

This publication serves as a public disclosure of a potentially patentable invention, thereby dedicating it to the public domain and preventing any future patent claims on the described concept.

- **Note: Regional Vernacular Terms and Their Variability: Understanding the Limitations of Non-Standardised Expressions**

The terms *Susundi*, *Tadd*, *Neera*, and *Sungu Sungu* not only lack standardisation but also differ from established state and regional languages. Their meanings are often rooted in local dialects and can vary significantly across different communities and regions. As a result, these expressions may hold different interpretations depending on cultural context, making them informal and inconsistent for broader communication or academic use. It is essential to recognise that such terms, while meaningful within specific local settings, may not translate accurately or uniformly outside those areas.

- **Linguistic Variability of Local Terms: Divergence from Standard State and Regional Languages**

These terms also differ from standardised state and regional languages, often originating from local dialects or colloquial usage. Their meanings can vary significantly across different areas, making them informal and inconsistent when compared to officially recognised linguistic forms.

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Conflicts of Interest

The authors declare no conflict of interest.

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