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Middle East Research Journal of Medical Sciences
ISSN: 2789-7699 (Print) & ISSN: 2958-2024 (Online)
Frequency: Bi-Monthly
DOI: https://doi.org/10.36348/merjms.2026.v06i01.003

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Methanol-Related Intoxications from Adulterated Distilled Beverages in Brazil, 2017–2025: Clinical Outcomes, Public Health Impacts, and International Context

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Abstract: Alcohol-related intoxications associated with adulterated distilled beverages represent a persistent and preventable public health challenge worldwide, particularly in contexts characterized by informal alcohol markets, weak regulatory oversight, and limited product traceability. In Brazil, recurrent outbreaks of methanol poisoning have resulted in high lethality and severe, often irreversible sequelae, with a marked escalation in reported cases during 2025. This study analyzes methanol-related intoxications reported between 2017 and 2025, with emphasis on temporal trends, outbreak configuration, clinical severity, long-term outcomes, and structural risk factors shaping exposure and health system response. A qualitative synthesis of epidemiological surveillance data, official health communications, and peer-reviewed scientific literature was conducted to characterize fatal outcomes, permanent visual and neurological impairment, and health system responses to methanol poisoning events. The analysis also differentiates methanol intoxication from ethanol-related events, including exposures involving fuel or industrial ethanol and alcohol-based disinfectants, which gained relevance during the COVID-19 period due to increased availability and unsafe handling practices. The findings demonstrate that methanol poisoning, although less frequent than ethanol intoxication, is associated with disproportionately higher case fatality rates and a substantial burden of long-term disability among survivors. Visual impairment, including irreversible blindness, and persistent neurological deficits emerged as dominant sequelae, underscoring that the public health impact of these outbreaks extends well beyond acute mortality. Comparative evidence from international outbreaks highlights common structural determinants, including illicit production, informal distribution channels, delayed diagnosis, and fragmented surveillance systems. Overall, the study reinforces that methanol-related intoxications constitute a severe yet preventable public health problem. Strengthening integrated surveillance systems, regulatory enforcement, product traceability, laboratory capacity, and risk communication, particularly in vulnerable settings, is essential to prevent future outbreaks and mitigate avoidable harm.

Keywords: Adulterated beverages, Alcohol intoxication, Brazil, Ethanol exposure, Methanol poisoning, Public health, Toxic alcohols.

Research Paper

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How to cite this paper:
Marco Vinícios de Oliveira Santana *et al* (2026). Methanol-Related Intoxications from Adulterated Distilled Beverages in Brazil, 2017–2025: Clinical Outcomes, Public Health Impacts, and International Context. *Middle East Res J. Med. Sci, 6*(1): 29-45.

Article History:
| Submit: 30.12.2025 |
| Accepted: 02.02.2026 |
| Published: 05.02.2026 |

1.0.INTRODUCTION

Alcohol-related intoxications associated with adulterated distilled beverages represent a persistent and preventable public health challenge, particularly in settings characterized by informal alcohol markets, weak regulatory oversight, and limited product traceability. In recent years, an increasing number of poisoning episodes worldwide have been linked to methanol, a highly toxic alcohol not intended for human consumption and frequently detected in falsified or illicitly produced distilled beverages (Hay, 2017; Alrashed *et al.*, 2024). Methanol contamination commonly arises from illicit production practices, substitution with industrial alcohols, or inadequate quality control within informal supply chains, substantially increasing the risk of mass exposure.

In contrast to ethanol intoxication, which is typically dose-dependent and often reversible, methanol

poisoning is characterized by delayed symptom onset and rapid metabolic deterioration due to the accumulation of toxic metabolites, particularly formic acid (Barceloux *et al.*, 2000; Kraut and Mullins, 2018). The clinical evolution frequently includes severe metabolic acidosis, visual impairment resulting from optic nerve toxicity, and neurological damage involving the central nervous system. Once symptoms become clinically apparent, disease progression may be rapid, often leading to irreversible sequelae or death if timely treatment is not initiated. The nonspecific nature of early manifestations—commonly resembling uncomplicated ethanol intoxication or alcohol hangover contributes to diagnostic delays and worsens clinical outcomes (Anvisa, 2025; Brazil Agency, 2025a; CNN Brazil, 2025b).

Methanol-related outbreaks reported in Brazil during 2025 raised significant concern among health authorities due to the number of fatalities and cases of permanent disability documented. These events exposed persistent vulnerabilities in surveillance systems, regulatory enforcement, and risk communication, particularly in contexts dominated by informal alcohol markets and limited traceability. Collectively, this scenario reinforced the classification of these episodes as public health emergencies and underscored the urgent need for integrated strategies aimed at early detection, prevention, and coordinated outbreak response (Figure 1) (Anvisa, 2025; Brazil Agency, 2025a; CNN Brazil, 2025b).

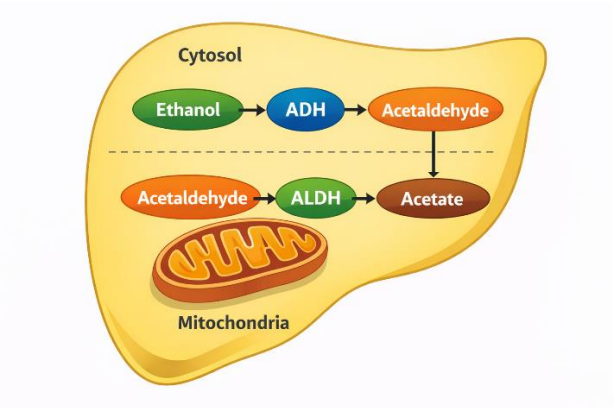

Figure 1: Hepatic metabolism of ethanol. Ethanol is oxidized to acetaldehyde by alcohol dehydrogenase (ADH) in the cytosol, and acetaldehyde is subsequently converted to acetate by Aldehyde Dehydrogenase (ALDH) in the mitochondria

Brazil has reported multiple episodes of alcohol-related intoxication over recent decades, with outbreaks frequently associated with the illicit production and distribution of distilled beverages (Hay, 2017; Manning and Kowalska, 2021; Bryan *et al.*, 2024). These events have been documented across different regions of the country and have disproportionately affected socially vulnerable populations, often occurring outside regulated commercial channels where product quality control, consumer protection, and effective traceability mechanisms are limited (OECD, 2022; Movendi International, 2025). Such conditions facilitate the circulation of adulterated beverages and hinder timely detection by regulatory and health surveillance systems.

Surveillance data and clinical reports consistently indicate that methanol-related poisonings, although less frequent than ethanol intoxication, are associated with substantially higher lethality and more severe clinical outcomes (Zakharov *et al.*, 2014; Gulen *et al.*, 2020; Alhusain *et al.*, 2024). Periodic surges in reported cases suggest persistent failures in enforcement, product traceability, and early identification of contaminated beverages within informal markets. These gaps have been highlighted by national and international public health agencies and media reports documenting recurrent episodes of blindness, neurological damage, and death associated with methanol-laced alcohol (Anvisa, 2025; Food Safety News, 2025; The Guardian, 2025).

Epidemiological estimates further indicate that approximately 13.8% of all alcohol consumed in the Americas is unrecorded, encompassing informal, illicit, and surrogate products. This substantial proportion of unregulated consumption markedly increases the risk of exposure to toxic contaminants such as methanol, particularly in settings characterized by weak regulatory oversight and limited surveillance capacity (PAHO/WHO, 2025). Comparative analyses consistently demonstrate that case fatality rates associated with methanol intoxication are significantly higher than those observed for ethanol-related poisoning, reflecting both fundamental toxicological differences and frequent delays in diagnosis and treatment (Kraut and Mullins, 2018; Salehtabari *et al.*, 2025).

Beyond national contexts, methanol poisoning constitutes a significant global public health problem. Estimates from Médecins Sans Frontières suggest that approximately 40,000 individuals worldwide have been

affected by methanol intoxication since 1998, resulting in an estimated 14,400 deaths, although these figures likely underestimate the true burden due to underdiagnosis and incomplete surveillance (MSF Norway *et al.*, 2019). International public health alerts emphasize that recurrent methanol outbreaks represent a largely preventable cause of mortality and long-term disability, underscoring the need for coordinated surveillance systems, regulatory action, and public awareness strategies at both national and international levels (Hay, 2017; Nekoukar *et al.*, 2021; Movendi International, 2025).

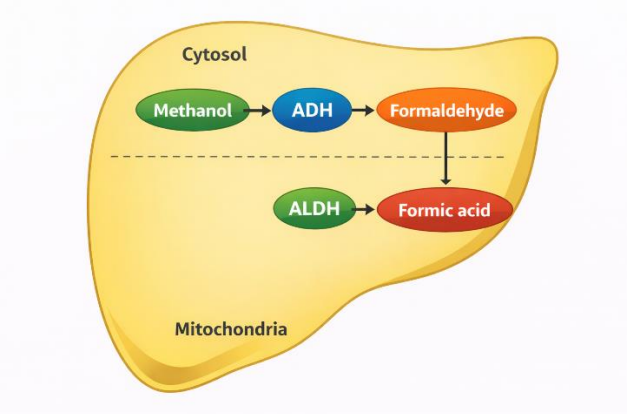

Figure 2: Hepatic metabolism of methanol. Methanol is oxidized to formaldehyde by Alcohol Dehydrogenase (ADH) in the cytosol, and formaldehyde is subsequently converted to formic acid by Aldehyde Dehydrogenase (ALDH), leading to the accumulation of the toxic metabolite

Within this context, the present study aims to analyze methanol-related intoxications associated with adulterated distilled beverages in Brazil between 2017 and 2025, with particular emphasis on the outbreak configuration observed in 2025. The study seeks to characterize clinical severity through qualitative outcomes, including deaths and permanent sequelae such as visual and neurological impairment. Additionally, it aims to differentiate methanol intoxication from ethanol-related events, including exposures involving fuel or industrial ethanol and alcohol-based disinfectants. Finally, a structured review of the scientific literature by thematic area is conducted to support prevention strategies, regulatory actions, and risk communication in vulnerable contexts

2.0. METHODS

This study employed a descriptive and analytical design to investigate alcohol-related intoxications associated with methanol-contaminated distilled beverages in Brazil from 2017 to 2025. Data were obtained from official health surveillance systems, epidemiological bulletins, and publicly available clinical reports issued by national and state health authorities. Confirmed and probable cases were included, and outcomes were classified according to mortality and the presence of permanent sequelae, such as visual or neurological impairment. Ethanol-related intoxications were considered solely for contextual comparison and were not included in outcome calculations.

Data extraction followed a standardized protocol to ensure consistency across sources, including verification of duplicated notifications and exclusion of records with incomplete outcome information. Cases were stratified by year, geographic region, and clinical outcome to allow temporal and regional comparisons. The literature review component involved the systematic identification of scientific articles relevant to methanol intoxication, which were subsequently categorized by disciplinary area. This approach enabled an integrated analysis combining epidemiological surveillance data with scientific evidence. All analyses were conducted using descriptive statistical techniques appropriate for observational public health data.

3.0. RESULTS

Between 2017 and 2025, alcohol adulteration events in Brazil were consistently associated with severe clinical outcomes and a substantial burden of long-term morbidity. During the major methanol outbreak reported in 2025, the Brazilian Ministry of Health officially confirmed 47 cases of methanol intoxication, with an additional 57 suspected cases remaining under epidemiological investigation. As of October 20, 2025, nine deaths had been confirmed, while seven further deaths were still under investigation, indicating a lethality profile markedly higher than that observed in typical ethanol-related intoxications. Among individuals who survived acute methanol poisoning, permanent sequelae were frequently documented, most notably visual impairment and neurological dysfunction. Importantly, official surveillance systems did not provide consolidated quantitative estimates of long-term outcomes, reflecting structural limitations in post-acute follow-up and outcome reporting.

A comparable toxic alcohol event not involving methanol further illustrates the persistent and multifaceted burden associated with alcohol

adulteration. In the Backer brewery case in Minas Gerais, contamination of beer with monoethylene glycol and diethylene glycol resulted in ten confirmed deaths. Five years after the exposure, multiple survivors continue to experience permanent sequelae, including chronic kidney disease, visual and auditory deficits, facial paralysis, and neurological impairment. In several instances, these long-term effects prevented affected individuals from returning to their previous occupational activities. Together, these observations demonstrate that the health impact of alcohol adulteration extends well beyond acute mortality, generating sustained disability and long-lasting social and economic consequences (Table 1).

Table 1: Comparative summary of major alcohol adulteration events in Brazil, indicating the main adulterants, affected regions, and associated health impacts. The table highlights recurring patterns and public health implications related to alcohol contamination

Event	Year(s)	Toxic agent	Cases/deaths	Key health impacts
Methanol outbreak (Brazil)	2025	Methanol	47 cases; 9 deaths	Metabolic acidosis, blindness, and neurological impairment
Methanol outbreak (Brazil)	2025	Methanol	57 cases under investigation	Visual toxicity and CNS involvement
Backer Brewery case (Minas Gerais)	2020–2025	Monoethylene glycol	Multiple cases	Acute kidney injury
Backer Brewery case (Minas Gerais)	2020–2025	Diethylene glycol	10 deaths	High lethality and neurological damage
Backer Brewery case (Minas Gerais)	2020–2025	Glycol compounds	Included above	Chronic kidney disease and sensory deficits

The temporal analysis of alcohol-related intoxications associated with methanol-contaminated distilled beverages between 2017 and 2025 revealed a heterogeneous distribution pattern. Earlier years were characterized predominantly by sporadic or isolated notifications, whereas a pronounced escalation in reported cases occurred in 2025. This latter period exhibited features consistent with a clear outbreak configuration rather than a continuation of isolated or endemic events, suggesting a concentrated point-source exposure. Compared with preceding years, the intensity of reported cases in 2025 substantially exceeded baseline levels described by health authorities. This temporal pattern supports the epidemiological classification of the 2025 episode as an acute public health emergency rather than a persistence of low-level endemic occurrence (Table 2).

Table 2: Temporal pattern of methanol-related intoxication events in Brazil (2017–2025). This table summarizes the qualitative temporal distribution of reported methanol intoxication events, highlighting shifts in occurrence intensity, regulatory context, and epidemiological interpretation

Period	Occurrence pattern	Regulatory and market context	Epidemiological interpretation	Public health implications
2017–2018	Isolated notifications	Routine surveillance; limited visibility of illicit chains	No outbreak configuration; case-based detection	Low signal-to-noise; high risk of under-detection
2019	Sporadic reports	Informal market persistence ; inconsistent enforcement	Early warning signals for adulteration	Need for targeted vigilance and lab readiness
2020	Low but persistent	Pandemic-era constraints; reduced inspections and shifts to informal sales	Sustained low-level exposure potential	Higher likelihood of delayed care and late diagnosis
2021	Low but persistent	Variable municipal capacity; continued circulation of falsified products	Continued risk without clear clustering	Opportunities for strengthening toxico-surveillance
2022	Moderate increase	Fragmented responses; ongoing counterfeit distribution	Emerging cluster-compatible pattern	Need for rapid differentiation from ethanol intoxication
2023	Moderate increase	Intermittent enforcement ; persistent informal availability	Expansion of exposure networks	Cross-sector coordination becomes critical
2024	Pre-outbreak escalation	Delayed corrective actions; limited traceability of products	High outbreak potential; sentinel events	Proactive alerts and intensified inspections are recommended

Period	Occurrence pattern	Regulatory and market context	Epidemiological interpretation	Public health implications
2025	Outbreak peak	Emergency interventions; intensified seizures and public alerts	Point-source exposure; public health emergency	High lethality and sequelae burden; urgent risk communication

Regarding clinical outcomes, fatal cases were frequently reported during the 2025 outbreak, demonstrating a lethality profile substantially more severe than that typically associated with ethanol-related intoxications. Mortality was consistently described as elevated in official communications and clinical summaries, reinforcing the extreme toxicity of methanol when ingested. Deaths commonly followed rapid clinical deterioration after a delayed onset of symptoms, a hallmark of methanol poisoning related to the accumulation of toxic metabolites. These findings highlight the disproportionate contribution of methanol exposure to fatal alcohol-related outcomes despite its comparatively lower prevalence relative to ethanol consumption (Table 3).

Table 3: Clinical outcomes and severity markers associated with methanol intoxication. The table synthesizes outcome categories, typical severity indicators, and clinical relevance, supporting differentiation from ethanol intoxication in emergency settings

Outcome/marker	Relative frequency (qualitative)	Severity level	Clinical relevance	Typical care needs
Fatal outcome	High in outbreak settings	Extreme	Key driver of outbreak burden	Critical care; advanced support
Severe metabolic acidosis	High	Critical	Proxy for advanced poisoning and poor prognosis	ICU monitoring; dialysis consideration
Visual impairment (blurred vision/scotomas)	High	Severe	Hallmark of methanol metabolism	Ophthalmology; antidote; monitoring
Complete blindness	Moderate	Severe	Irreversible disability in many cases	Rehabilitation; long-term support
Neurological deficits	Moderate	Moderate–severe	Cognitive/motor impairment; functional loss	Neuro rehab; multidisciplinary care
Respiratory compromise	Low–moderate	Severe	Often secondary to critical illness	Ventilatory support when needed
Renal complications (secondary)	Low–moderate	Moderate	May reflect multi-organ dysfunction	Nephrology follow-up
Survival without sequelae	Low	Mild	Uncommon full recovery in severe outbreaks	Observation; follow-up

Among individuals who survived the acute intoxication phase, permanent sequelae were commonly reported. Visual impairment emerged as the most frequently documented long-term consequence, ranging from partial visual loss to irreversible blindness. Neurological sequelae, including cognitive deficits and motor dysfunction, were also observed, although less frequently than ophthalmologic damage. Several reports described the coexistence of multiple sequelae within the same individual, indicating multisystem injury. The high prevalence of long-term disability among survivors underscores that the burden of methanol intoxication extends far beyond immediate mortality and persists as a chronic health and social challenge (Table 4).

Table 4: Permanent sequelae reported among survivors of methanol intoxication. This table highlights multisystem long-term complications and their functional consequences, emphasizing the disability burden beyond mortality

Sequela type	Affected system	Functional impact	Clinical significance
Partial visual loss	Ophthalmologic	Reduced acuity; impaired reading/driving	Common disabling outcome
Complete blindness	Ophthalmologic	Total vision loss; dependence risk	Permanent disability; major social impact
Optic neuropathy	Ophthalmologic/neurologic	Persistent visual-field defects	Typical methanol signature
Cognitive impairment	Central nervous system	Memory/attention deficits; reduced autonomy	Long-term rehabilitation needs
Motor dysfunction	Neuromuscular	Gait disturbance, weakness, and coordination loss	Chronic mobility limitations

Sequela type	Affected system	Functional impact	Clinical significance
Speech/language difficulties	Neurologic	Communication impairment	Impacts employability and social functioning
Psychiatric symptoms	Neuropsychiatric	Anxiety/depression; adjustment disorders	Often under-recognized; needs follow-up
Functional dependence	Multisystem	Reduced ability for daily living activities	Drives long-term care demand

Sociodemographic and geographic characterization of reported cases suggested a non-random distribution of exposures. A higher concentration of cases was observed in specific regions and states, consistent with the localized circulation of contaminated beverage batches. Reports frequently involved socially vulnerable populations, particularly individuals with limited access to regulated commercial products and delayed healthcare-seeking behavior. These patterns indicate that structural, economic, and social determinants played a central role in shaping both exposure risk and clinical outcomes during the outbreak period (Table 5).

Table 5: Geographic and sociodemographic vulnerability patterns associated with methanol intoxication. The table summarizes clustering, vulnerable settings, and contextual determinants relevant to prevention strategies

Distribution aspect	Observed pattern	Likely determinant	Prevention implication
Geographic clustering	Concentration in specific states/municipalities	Localized distribution of contaminated batches	Target inspections and traceability actions
Informal purchase settings	Non-licensed points of sale	Price sensitivity and access barriers to regulated products	Improve consumer guidance and enforcement
Social vulnerability	Higher occurrence in low-income contexts	Economic constraints; limited information access	Risk communication tailored to vulnerable groups
Delayed care seeking	Late presentation to services	Low risk perception; access barriers	Early warning messages and triage protocols
Mass social events	Clusters tied to gatherings	Shared consumption of contaminated beverages	Rapid cluster detection and alerts
Occupational vulnerability	Occasional links to informal work contexts	Exposure in social/occupational gatherings	Workplace/community outreach
Urban peripheries	Higher reported risk	Informal market penetration	Community-level engagement
Rural/remote areas	Under-detection risk	Limited diagnostic capacity and transport barriers	Strengthen referral and laboratory networks

Analysis of exposure circumstances indicated that the majority of intoxications were associated with suspected illicit or falsified distilled beverages. In many cases, the precise origin of the consumed products could not be confirmed due to a lack of traceability, reuse of containers, or absence of appropriate labeling. Consumption often occurred in informal social settings rather than licensed establishments, complicating early detection and timely intervention. These exposure characteristics are consistent with point-source outbreaks linked to contaminated batches distributed through informal markets (Table 6).

Table 6: Exposure characteristics, product origin, and regulatory infractions related to methanol-contaminated beverages. This table describes common exposure pathways, product features, and infringementention

Exposure component	Typical description	Common infractions/irregularities	Risk implication
Product type	Distilled spirits (varied categories)	Mislabeling of content and origin	Higher methanol concentration risk
Origin	Illicit or falsified products	Lack of producer identification; counterfeit branding	No traceability; delayed recalls
Packaging	Reused bottles/irregular seals	Absence of tax seal; tampered caps	Consumer unable to verify authenticity
Distribution channel	Informal markets; peer-to-peer sales	Sales without licensing; no invoices	Rapid spread before detection
Price signals	Below-market pricing	Predatory pricing in illicit trade	Attracts vulnerable consumers

Exposure component	Typical description	Common infractions/irregularities	Risk implication
Label information	Incomplete or inconsistent	Missing batch numbers; falsified addresses	Blocks source tracking
Adulteration motive	Increase perceived alcohol strength	Use of industrial alcohols	Severe toxicity and mass casualties
Traceability failure	Unknown batch and supply chain	Non-compliance with recordkeeping	Limits outbreak containment

Indicators related to health system response reflected the severity of the outbreak. A substantial proportion of affected individuals required hospital admission, and intensive care was frequently necessary in severe cases. Official responses included product seizures, interdictions, and public risk alerts; however, these measures were often implemented only after multiple severe cases had already occurred. The interval between initial case notifications and large-scale public warnings varied, highlighting operational challenges in outbreak recognition, surveillance sensitivity, and intersectoral response coordination (Table 7).

Table 7: Health system response and regulatory actions during methanol intoxication outbreaks. The table summarizes clinical management components, surveillance actions, and enforcement measures, highlighting operational challenges and opportunities for improvement

Response domain	Observed actions	Operational challenges	Improvement opportunity
Emergency triage	Recognition of toxic alcohol patterns	Misclassification as ethanol intoxication	Standardized triage prompts and checklists
Laboratory capacity	Assessment of acidosis and supportive labs	Limited access to confirmatory testing	Expand regional toxicology lab networks
Antidotal therapy	Use of alcohol dehydrogenase inhibitors/support	Availability and timing variability	Protocols and stock management
Extracorporeal treatment	Dialysis in severe cases	Resource constraints and referral delays	Regional referral pathways and criteria
Hospitalization/ICU	High demand in outbreak peaks	Bed and staff saturation	Surge capacity planning
Risk communication	Public alerts and guidance	Delayed dissemination to high-risk groups	Faster multi-channel alert systems
Regulatory enforcement	Seizures/interdictions and inspections	Fragmented inter-agency coordination	Joint operations and traceability enforcement
Case reporting	Notification to surveillance systems	Incomplete follow-up outcomes	Improve follow-up documentation routines

The literature review component identified a heterogeneous body of scientific publications addressing methanol intoxication. Most studies were concentrated in toxicology and clinical medicine, focusing primarily on pathophysiology, diagnosis, and acute management. In contrast, public health and epidemiological analyses were less frequent, and studies addressing regulation, prevention strategies, and risk communication were comparatively scarce. This distribution reflects a predominance of biomedical perspectives in the literature and a relative underrepresentation of systemic, preventive, and policy-oriented approaches (Table 8).

Table 8: Scientific literature analyzed by thematic area and research gaps. This table synthesizes the dominant disciplinary focus in the reviewed literature and highlights areas requiring strengthened evidence

Thematic area	Typical study focus	Common study designs	Key gap/research need
Toxicology	Mechanisms; metabolism; prognostic markers	Reviews: experimental/clinical series	Limited translation into prevention frameworks
Clinical medicine	Diagnosis; treatment; acute outcomes	Retrospective cohorts; case series	Scarce long-term sequelae follow-up
Ophthalmology	Visual outcomes: optic neuropathy	Case series; clinical reviews	Need standardized outcome measurement
Neurology	Neuroimaging and cognitive outcomes	Observational studies	Underrepresentation of rehabilitation pathways
Public health	Outbreak characterization: determinants	Descriptive reports; surveillance analyses	Few evaluations of interventions
Regulation and policy	Control measures; illicit trade	Policy analyses	Limited empirical impact assessments

Thematic area	Typical study focus	Common study designs	Key gap/research need
Risk communication	Messaging strategies and behaviors	Qualitative studies	Low volume of context-specific research
Forensic/analytics	Detection of adulteration and counterfeits	Method development	Need scalable field deployment studies

Differentiation between beverage-grade ethanol intoxication and exposures involving fuel or industrial ethanol revealed distinct exposure pathways and public health implications. Non-beverage ethanol exposures were predominantly associated with unsafe storage practices, container reuse, and deliberate substitution in informal contexts. These events differ from conventional ethanol intoxication by presenting additional risks related to impurities, denaturants, and the absence of traceability, complicating surveillance and outbreak investigation (Table 9).

Table 9: Differentiation between beverage-grade ethanol and fuel/industrial ethanol exposures in alcohol-related intoxication events. This table summarizes key distinctions between ethanol intended for human consumption and ethanol intended for industrial or fuel purposes, emphasizing exposure pathways and implications for surveillance and prevention

Substance/source	Intended use	Key characteristics	Typical misuse/exposure scenario	Public health implication
Beverage-grade ethanol	Human consumption	Food-grade production; quality control	Excessive drinking; binge episodes	High population burden; outcomes often dose-dependent
Fuel ethanol (ethanol fuel)	Automotive fuel	Not food-grade; potential impurities/adulteration	Accidental ingestion from fuel containers; repurposed storage	Severe poisoning risk; requires rapid differentiation from beverage ethanol
Industrial/denatured ethanol	Solvent/disinfection/industrial processes	May contain denaturants/impurities; not for ingestion	Intentional ingestion as a substitute for alcohol; accidental ingestion	Unpredictable toxicity; surveillance should capture non-beverage alcohol exposure
Alcohol-based products (unknown grade)	Variable	Traceability is absent in informal settings	Use in falsified drinks or unregulated handling	Complicates outbreak investigation and traceability

During the COVID-19 period, alcohol-based products widely used for disinfection emerged as an additional source of intoxication risk. Accidental ingestion, particularly among children, and unsafe decanting practices were repeatedly identified as exposure routes. Although distinct from illicit beverage outbreaks, these events contributed to severe intoxications and increased demand for emergency medical care (Table 10).

Table 10: Alcohol-based products widely used for disinfection during COVID-19 and associated intoxication risks. This table synthesizes common alcohol-based disinfection products, intended uses, exposure routes, and prevention messages relevant to poisoning risk during periods of high household and occupational use

Product type	Typical use	Common exposure routes	Main poisoning concern	Prevention message
Alcohol gel hand sanitizer	Hand hygiene	Accidental ingestion (children); intentional ingestion	Ethanol/isopropanol intoxication; contamination risk in poor-quality products	Store safely; do not ingest; prefer regulated products
Liquid hand sanitizer / rubbing alcohol	Hand hygiene: quick cleaning	Ingestion; inhalation in poorly ventilated spaces	High-dose intoxication; irritant effects	Use with ventilation; keep away from food containers
Alcohol-based surface disinfectants	Cleaning tools/surfaces	Dermal contact; inhalation; accidental ingestion	Irritation; misuse as an average substitute	Clear labeling; never ingest; avoid decanting to drink bottles
Alcohol is used to disinfect tools/materials	Household/occupational cleaning	Accidental ingestion due to unsafe storage practices	Confusion with potable liquids; high-dose exposure	Never store in beverage containers; keep original packaging
Refill/decanted alcohol products	Convenience storage	Ingestion from unlabeled containers	Unknown concentration; mixed products	Maintain labels; child-proof storage; discard unknown products

Finally, analysis of exposure characteristics combined with international evidence indicated that distilled beverages are disproportionately represented in methanol adulteration events. Products such as vodka, gin, cachaça, whisky, rum, tequila, and cognac were consistently implicated in outbreak investigations due to high market demand, ease of falsification, and the ability of strong flavors to mask adulteration. In contrast, fermented beverages such as beer, draft beer, and wine typically generate minimal methanol during production, although adulteration remains possible in informal markets. Selected international outbreaks further illustrate the global recurrence of methanol-related intoxication and its severe clinical consequences (Table 11).

Table 11: Alcoholic beverages most susceptible to methanol adulteration and selected international outbreaks. This table summarizes the alcoholic beverage categories most frequently associated with methanol adulteration, with an emphasis on distilled spirits commonly implicated in large-scale poisoning events

Category	Description	Public health relevance
Distilled beverages at the highest risk	Vodka, gin, cachaça, whisky, rum, tequila, and cognac are frequently reported in methanol adulteration cases due to high demand and ease of falsification.	High outbreak potential with severe toxicity, blindness, and death.
Fermented beverages	Beer, draft beer, wine, and cider usually contain minimal methanol from fermentation, but may be adulterated in informal markets.	Lower baseline risk but still relevant for surveillance.
Russia (2016; 2025)	Surrogate alcohol and adulterated beverages containing methanol caused dozens of deaths in Irkutsk and the Leningrad region.	Illustrates extreme lethality and repeated outbreaks.
India (Punjab, 2025)	Illicit locally produced alcohol contaminated with methanol led to multiple deaths and hospitalizations.	Shows persistence of outbreaks in informal production systems.
Indonesia and Malaysia (2018)	Illegal alcoholic beverages adulterated with methanol caused over 80 deaths and more than 140 hospitalizations.	Demonstrates large-scale outbreak capacity.
Spain (1963)	The historic methanol adulteration scandal resulted in deaths and widespread blindness.	Classic example of long-term sequelae.
Cuba (2013–2014)	The illegal methanol trade caused the intoxication of over one hundred people; perpetrators received long prison sentences.	Highlights criminal accountability and deterrence.

Category	Description	Public health relevance
Turkey (2025)	Large-scale methanol poisoning outbreaks reported in major urban centers, including Istanbul (approximately 235 cases) and Ankara (approximately 94 cases), associated with adulterated alcoholic beverages.	Illustrates persistence of high-magnitude outbreaks despite regulatory frameworks.

In contrast, fermented beverages such as beer, draft beer, and wine typically generate minimal methanol during production; however, adulteration remains a possibility in informal markets. The table also presents selected international outbreaks illustrating the global recurrence of methanol-related intoxication, including events in Europe, Asia, and Latin America, which resulted in high mortality, irreversible visual impairment, and significant neurological sequelae. Together, these examples highlight common structural determinants such as illicit production, weak regulatory oversight, and limited traceability that underlie methanol poisoning outbreaks worldwide and reinforce their relevance as a preventable public health problem.

Analysis of exposure characteristics and international evidence indicates that distilled beverages are disproportionately represented in methanol adulteration events, particularly vodka, gin, cachaça, whisky, rum, tequila, and cognac. These products were consistently reported in outbreak investigations due to their high market demand, ease of falsification, and the ability of strong flavors to mask adulteration. In contrast, fermented beverages such as beer, draft beer, and wine generally present minimal methanol formation during production, although adulteration remains possible in informal markets. A comparative overview of beverages at highest risk and selected international outbreaks associated with methanol-contaminated alcohol is presented in Table 11.

Taken together, these findings provide a comprehensive descriptive framework that supports a broader interpretative discussion on the clinical severity, structural determinants, and public health implications of methanol-related alcohol adulteration.

4.0. DISCUSSION

The present findings reinforce that methanol-related intoxication represents one of the most severe forms of alcohol poisoning, distinguished by high lethality and irreversible clinical outcomes (Hay, 2017; Nekoukar *et al.*, 2021; Alrashed *et al.*, 2024). Unlike ethanol intoxication, which is often dose-dependent and generally reversible, methanol exposure leads to delayed but profound metabolic toxicity driven by the accumulation of formic acid and the subsequent development of severe metabolic acidosis (Barceloux *et al.*, 2002; Kraut and Mullins, 2018). International outbreak alerts further corroborate the clinical patterns observed in this analysis, consistently describing a characteristic delay of 2 to 48 hours between ingestion and symptom onset.

Gastrointestinal complaints, visual disturbances, progressive metabolic acidosis, and neurological deterioration typically follow this latent period. The nonspecific nature of early symptoms frequently contributes to under-recognition of methanol poisoning, particularly when manifestations resemble those of alcohol hangover or uncomplicated ethanol intoxication. Such diagnostic delays significantly worsen prognosis and increase the likelihood of irreversible sequelae or death, reinforcing the need for heightened clinical suspicion during outbreak situations (PAHO/WHO, 2025).

The outbreak pattern observed in 2025 supports the interpretation of point-source contamination linked to adulterated batches rather than sporadic individual exposure, a configuration consistently reported in large-scale methanol outbreaks across different geographic settings (Zakharov *et al.*, 2014; Gulen *et al.*, 2020). Similar outbreak dynamics have been documented in diverse international contexts, underscoring the global relevance of this preventable public health problem and highlighting the need for coordinated surveillance systems, regulatory enforcement, and rapid risk communication strategies (Figure 3) (Manning and Kowalska, 2021; Movendi International, 2025).

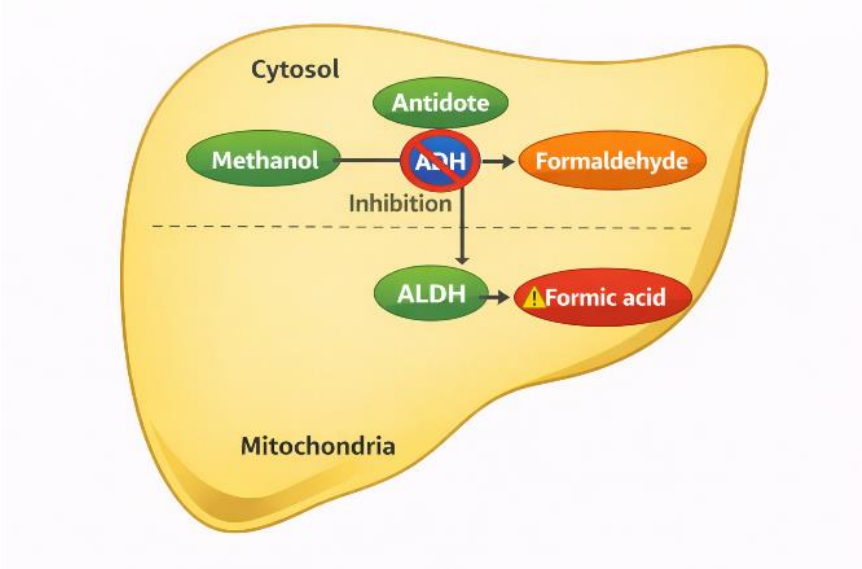

Figure 3: Metabolic basis of antidotal therapy in methanol poisoning. Preferential binding of the antidote to Alcohol Dehydrogenase (ADH) inhibits the conversion of methanol to formaldehyde, thereby reducing downstream formation of the toxic metabolite formic acid

The predominance of permanent sequelae among survivors, particularly visual impairment and neurological damage, highlights the substantial long-term burden imposed by methanol poisoning (Zakharov *et al.*, 2014; Rym *et al.*, 2023; Fedrigo *et al.*, 2025). Visual toxicity remains a defining clinical hallmark of methanol intoxication, frequently progressing to irreversible blindness even when acute survival is achieved. This outcome reflects the marked vulnerability of the optic nerve and visual pathways to methanol metabolites, particularly formic acid, which disrupts mitochondrial function and cellular energy metabolism (Luo *et al.*, 2022; Nagendran *et al.*, 2025).

Neurological sequelae further compound the burden of disease by affecting functional independence and overall quality of life through persistent cognitive, sensory, and motor impairments (Nikoo *et al.*, 2022; Simani *et al.*, 2022). In several cases, visual and neurological deficits coexist, indicating multisystem injury and reinforcing the complexity of post-acute care needs. Collectively, these outcomes demonstrate that mortality alone substantially underestimates the true impact of methanol outbreaks, which extend into chronic health, social, and economic domains and impose sustained demands on healthcare systems, rehabilitation services, and long-term social support structures (Figure 4) (Hay, 2017; Alhusain *et al.*, 2024).

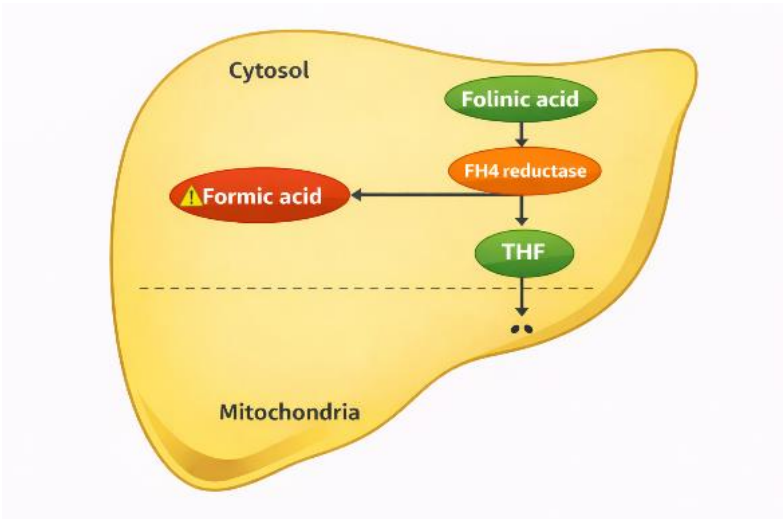

Figure 4: Role of folinic acid in the metabolism of formic acid during methanol poisoning. Folinic acid enhances the folate-dependent pathway, promoting the conversion and clearance of formic acid through tetrahydrofolate (THF)–mediated reactions, thereby reducing the accumulation of the toxic metabolite

Geographic clustering and the concentration of cases among socially vulnerable populations emphasize the central role of structural determinants in shaping exposure risk to methanol-contaminated beverages (Manning and Kowalska, 2021; OECD, 2022; Movendi International, 2025). Informal alcohol markets, limited regulatory oversight, and persistent economic constraints facilitate the circulation of illicit beverages and delay access to timely healthcare services, thereby amplifying both exposure risk and clinical severity once intoxication occurs (Alrashed *et al.*, 2024; Bryan *et al.*, 2024). In these contexts, delayed diagnosis and restricted access to specialized care further exacerbate outcomes, particularly during outbreak situations.

The recurrence of such outbreaks suggests persistent gaps in surveillance systems and intersectoral coordination, especially in settings characterized by fragmented regulatory capacity and limited traceability of alcohol products (MSF Norway *et al.*, 2019; Anvisa, 2025). These findings align with international evidence indicating that methanol poisoning is more closely linked to social inequality, informal market dynamics, and regulatory fragility than to individual consumption behavior alone. This reinforces the need for structural prevention strategies that address upstream determinants of risk, including enforcement, traceability, and public risk communication (Figure 5) (Hay, 2017; Nekoukar *et al.*, 2021).

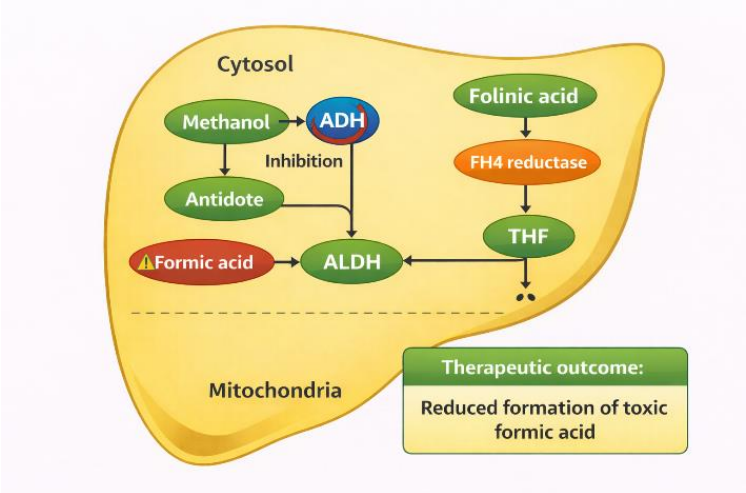

Figure 5: Role of bicarbonate therapy in methanol poisoning. Accumulation of formic acid leads to metabolic acidosis, which is counteracted by bicarbonate administration, promoting partial restoration of systemic pH balance

The predominance of distilled beverages in methanol-related outbreaks observed in this study is consistent with international evidence, which identifies spirits as the primary vehicles for large-scale poisoning events due to their higher alcohol content and susceptibility to adulteration (Hay, 2017; Bryan *et al.*, 2024). Historical and contemporary outbreaks reported in Europe, Asia, and Latin America demonstrate that vodka, whisky, gin, and locally produced spirits are frequently implicated, often as a result of illicit production practices, substitution with industrial alcohols, and distribution through informal channels (Zakharov *et al.*, 2014; Gulen *et al.*, 2020; Manning and Kowalska, 2021).

The alert also reinforces standardized management strategies for suspected methanol intoxication, emphasizing the need for early clinical recognition and prompt therapeutic intervention. Recommended measures include the immediate initiation of alcohol dehydrogenase inhibition with fomepizole or pharmaceutical-grade ethanol, correction of metabolic acidosis, folate supplementation to enhance formate metabolism, and the timely use of hemodialysis in severe cases. Together, these interventions aim to limit the accumulation of toxic metabolites and reduce the risk of irreversible organ damage. These recommendations align closely with established international toxicology guidelines and underscore the importance of maintaining antidote availability, laboratory readiness, and clearly defined referral pathways during outbreak scenarios (PAHO/WHO, 2025).

The response of health authorities during the outbreak illustrates both progress and ongoing challenges in the detection and management of methanol poisoning events (Anvisa, 2025; Brazil Agency, 2025b; CNN Brazil, 2025). While the severity of clinical presentations prompted regulatory actions, product seizures, and public alerts, delays in widespread risk communication and coordinated intersectoral response were evident, potentially allowing continued exposure before effective containment was achieved (Food Safety News, 2025; Movendi International, 2025). According to statements from the Secretary of Health of the State of São Paulo, approximately 20 alcohol-related deaths represent an upper reference threshold, with values above this level indicating a critical epidemiological

situation requiring escalation of response. The exceedance of this threshold during the outbreak supports its classification as a public health emergency, underscoring the need for faster notification, integrated surveillance, and coordinated regulatory and clinical action to mitigate avoidable harm (Figure 6) (City Hall of São Paulo – COVISA, 2025; U.S. Embassy and Consulates in Brazil, 2025).

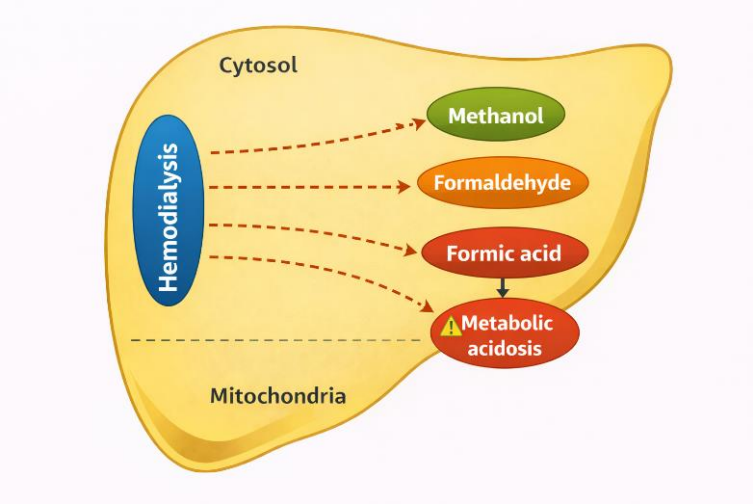

Figure 6: Role of hemodialysis in severe methanol poisoning. Hemodialysis facilitates the rapid removal of methanol, formaldehyde, and formic acid from the circulation, while also correcting metabolic acidosis, thereby reducing systemic toxicity

The widespread use of alcohol-based disinfectants during the COVID-19 pandemic introduced additional intoxication pathways unrelated to adulterated beverages. Reports worldwide documented severe poisonings linked to the ingestion of hand sanitizers, including cases involving contaminated, improperly formulated, or highly concentrated products. In Brazil, official alerts regarding inappropriate ingestion of non-beverage alcohols further highlighted the risks associated with increased availability, unsafe handling, and inadequate labeling of these products. Incorporating these exposure pathways into prevention strategies and risk communication is therefore crucial for reducing avoidable intoxications during public health emergencies (Holzman *et al.*, 2021; Mousavi-Roknabadi *et al.*, 2022; U.S. Department of Agriculture, 2025).

During the COVID-19 pandemic, several surveillance reports documented that up to 20–30% of reported toxic alcohol exposures were associated with non-beverage alcohol products, including hand sanitizers and industrial alcohols, highlighting the emergence of exposure pathways distinct from illicit alcoholic beverages (PAHO/WHO, 2025). These findings underscore the evolving landscape of toxic alcohol exposure and the need for adaptive surveillance strategies. Several limitations of this study must be acknowledged. The analysis relied on secondary data sources and narrative reports, which are subject to underreporting, incomplete follow-up, and regional variability in notification practices, particularly during outbreak situations (PAHO/WHO, 2025).

The absence of standardized national datasets precluded quantitative meta-analysis and precise estimation of mortality or sequelae rates, a challenge frequently reported in methanol outbreak investigations (Zakharov *et al.*, 2014; Güler *et al.*, 2024). Additionally, incomplete traceability of illicit products limited the reconstruction of exposure pathways and source attribution, constraining regulatory and enforcement analyses (OECD, 2022; Bryan *et al.*, 2024). Despite these constraints, the convergence of clinical, surveillance, and literature-based evidence supports the robustness of the observed patterns and their relevance for public health action (MSF Norway *et al.*, 2019; Anvisa, 2025).

Among survivors of acute methanol poisoning, international case series indicate that visual impairment affects approximately 30–60% of patients, with irreversible blindness reported in 10–30%, while persistent neurological sequelae occur in roughly 20–40% of cases. These figures underscore the substantial burden of long-term disability extending well beyond acute mortality and reinforce the need for sustained post-acute care and rehabilitation strategies (Figure 7) (PAHO/WHO, 2025).

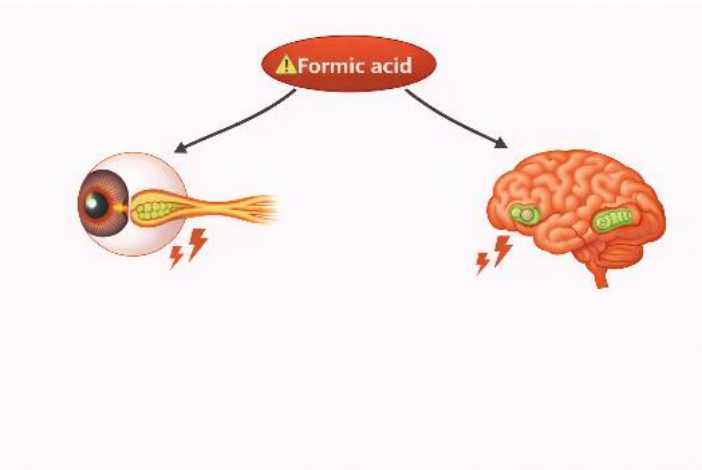

Figure 7: Pathophysiological effects of formic acid accumulation in methanol poisoning. Formic acid inhibits mitochondrial oxidative phosphorylation, particularly in tissues with high metabolic demand, such as the optic nerve and central nervous system, leading to visual impairment and neurological toxicity

Future perspectives should prioritize the development of harmonized surveillance systems capable of early detection of atypical alcohol poisoning clusters, thereby enabling rapid and accurate differentiation between ethanol- and methanol-related events (Hay, 2017; Nekoukar *et al.*, 2021). Early recognition of unusual clinical and epidemiological patterns is essential to prevent delays in diagnosis, reduce severe outcomes, and limit the scale of outbreaks. Strengthening laboratory capacity, including access to confirmatory testing and metabolic markers, alongside real-time data sharing and interdisciplinary collaboration between toxicology services, public health authorities, and regulatory agencies, is critical to improving outbreak response and reducing delays in clinical intervention (Kraut and Mullins, 2018; MSF Norway *et al.*, 2019). Such integration facilitates coordinated decision-making across clinical, surveillance, and enforcement domains.

International experience further indicates that integrated surveillance systems, when combined with robust traceability mechanisms and coordinated regulatory action, can substantially mitigate the impact of methanol outbreaks and prevent recurrence. Sustained investment in these structural measures has been shown to improve early warning capacity, enhance product recall efficiency, and strengthen public risk communication, ultimately reducing morbidity and mortality associated with toxic alcohol exposure (Figure 8) (Manning and Kowalska, 2021; OECD, 2022; Movendi International, 2025).

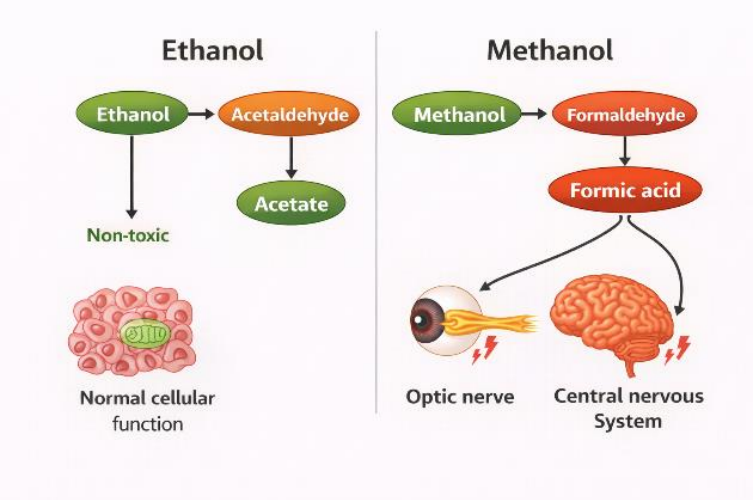

Figure 8: Comparative tissue toxicity of ethanol and methanol. Ethanol metabolism leads to acetate formation with preservation of normal cellular function, whereas methanol metabolism results in formic acid accumulation, which preferentially targets the optic nerve and central nervous system, causing mitochondrial dysfunction and tissue injury

Expanding research beyond clinical outcomes to include prevention strategies, risk communication approaches, and systematic policy evaluation may substantially reduce the recurrence and severity of future

methanol poisoning outbreaks (Manning and Kowalska, 2021; OECD, 2022; Movendi International, 2025). Evidence from international outbreak responses consistently suggests that sustained investments in regulation, product traceability, and public awareness are more effective than reactive, short-term interventions focused solely on acute clinical management (Hay, 2017; MSF Norway *et al.*, 2019; Bryan *et al.*, 2024). Addressing methanol intoxication, therefore, requires long-term structural interventions targeting informal alcohol markets, surveillance systems, and governance capacity, rather than reliance on emergency responses alone (Figure 9) (Nekoukar *et al.*, 2021; Alrashed *et al.*, 2024).

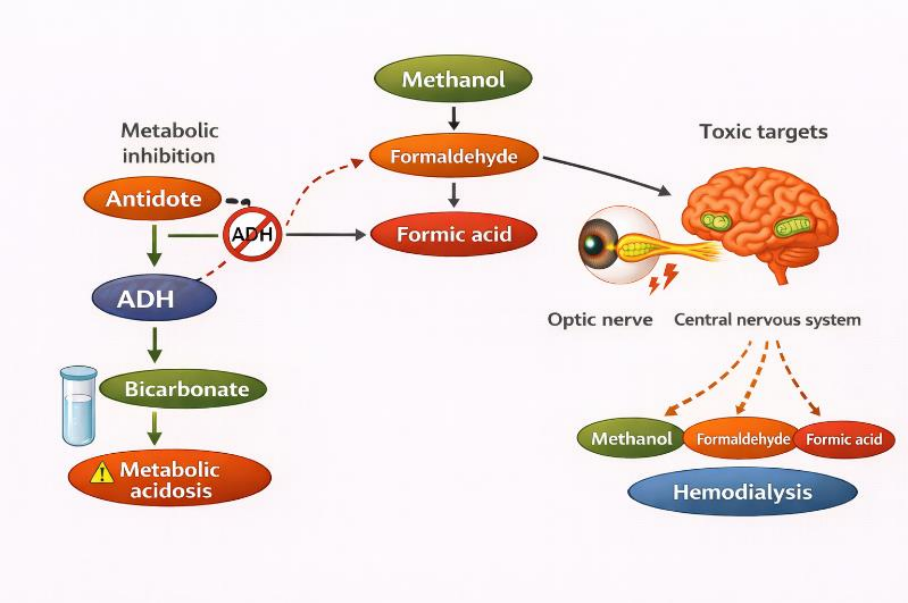

Figure 9: Integrated schematic of methanol poisoning management. Methanol is metabolized to formaldehyde and formic acid via alcohol dehydrogenase (ADH), a process inhibited by antidotal therapy. Accumulated formic acid targets the optic nerve and central nervous system, causing mitochondrial dysfunction. Supportive treatment includes bicarbonate for metabolic acidosis correction and hemodialysis for removal of methanol, formaldehyde, and formic acid

In outbreak settings, approximately one-third to one-half of affected patients require hemodialysis, reflecting the severity of metabolic acidosis and the need for rapid removal of methanol and its toxic metabolites (PAHO/WHO, 2025). Clinical alerts reinforce standardized management strategies for suspected methanol intoxication, including prompt initiation of alcohol dehydrogenase inhibition with fomepizole or pharmaceutical-grade ethanol, correction of metabolic acidosis, folate supplementation to enhance format clearance, and timely use of hemodialysis in severe cases. These recommendations are consistent with international toxicology guidelines and underscore the importance of maintaining antidote availability, laboratory readiness, and clearly defined referral pathways during outbreak scenarios (PAHO/WHO, 2025).

Published outbreak investigations further indicate that case fatality rates for methanol poisoning typically range from approximately 10% to over 30%, markedly exceeding those observed for ethanol-related intoxication, which generally remain below 1–2% in most surveillance settings (PAHO/WHO, 2025). Despite this severity, international experience indicates that methanol poisoning remains substantially underreported, as many outbreaks are never formally identified as methanol-related events, leading to systematic underestimation of incidence and mortality (MSF Norway *et al.*, 2019; Nekoukar *et al.*, 2021).

In Brazil, recent governmental actions, including the establishment of an intersectoral committee to address methanol intoxication, reflect growing institutional recognition of the need for coordinated surveillance, regulatory enforcement, and engagement with the alcoholic beverage sector (Anvisa, 2025; Brazil Agency, 2025b). While such initiatives represent important progress, international evidence suggests that sustained prevention depends on long-term investment in traceability systems, laboratory capacity, and effective risk communication, rather than reactive responses limited to outbreak periods (Hay, 2017; Manning and Kowalska, 2021; OECD, 2022).

5.0. CONCLUSION

Methanol-contaminated distilled beverages remain a severe yet preventable cause of alcohol-related intoxication, with outbreak configurations producing disproportionate mortality and a high burden of irreversible sequelae. The findings of this study demonstrate that the public health impact of methanol

poisoning extends well beyond acute deaths, encompassing permanent visual and neurological impairment with long-term social, economic, and healthcare consequences. These outcomes impose sustained demands on health systems, rehabilitation services, and social support structures, particularly in vulnerable populations.

The study also highlights the critical importance of differentiating methanol intoxication from ethanol-related events, including exposures involving fuel or industrial ethanol and alcohol-based disinfectants, which may present with overlapping clinical features but carry distinct toxicological risks. Failure to distinguish these exposure pathways can delay appropriate management and hinder effective surveillance and regulatory response. Strengthening integrated surveillance systems, regulatory enforcement, product traceability, and risk communication—especially within informal markets and socially vulnerable settings is essential to prevent future outbreaks and reduce avoidable harm. Coordinated public health action that combines clinical preparedness, laboratory capacity, regulatory oversight, and public awareness remains fundamental to mitigating the ongoing risk posed by toxic alcohol exposure and to preventing the recurrence of large-scale methanol poisoning events.

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