Beyond Sample Storage: Container-Induced Analyte Loss and Its Implications for Forensic Toxicological Analysis

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ABSTRACT

The quantity of a toxin analyzed in the lab depends on what was present in the specimen or sample during collection and the subsequent methods applied to the sample. This research examines the stability of hazardous substances in both investigative and clinical samples concerning a standard jar, its sealing method, and the storage conditions. This narrative review analyzes peer-reviewed articles found through specific searches of the indexed literature, verified by their original records, using 34 sources. No numerical risk-of-bias score was applied; the quality of the evidence was instead graded qualitatively (Table 2). Lipophilic medicines, particularly cannabis, have the strongest container evidence, indicating that adhering to plastic surfaces is a significant pathway for loss. Tetrahydrocannabinol losses were from 60 to 100% in polystyrene and 30 to 50% in glass when whole blood was stored at −20 °C for 4 to 24 weeks. The recoveries of eleven synthetic cannabinoids in oral fluid kept at room temperature for 72 h varied from 9 to 54% in polypropylene and from 84 to 114% in borosilicate glass. In urine, the amount of loss of the THC carboxylic acid metabolite depended on plastic type, solution's pH, exposure time, and internal bar-code labels, which showed a loss of almost 50%, compared to 14% for external ones. Storage temperature, freeze-thaw cycles, anticoagulants, antioxidants, and non-ionic surfactants were additional factors that needed consideration. Because almost all container comparisons concern cannabinoids, these are used as a model, and practical recommendations are limited to analyte–matrix–container combinations that have been validated. No container comparisons were found for metals, cyanide, volatile poisons, or traditional pesticides in the sources examined, so any extension of the cannabinoid findings to these toxicants remains an untested inference; this is a major limitation of the available literature.

Keywords: Forensic toxicology; sample vessels; adsorption loss; glass and plastic; biological specimens; additives

INTRODUCTION

A toxicological outcome represents a quantification of a sample, which is a chemical system that persistently develops from the moment it is collected. A specimen may undergo various processes such as traveling, waiting in storage, being frozen and thawed, and then re-tested months later for legal purposes between collection and analysis. During this period, the loss of the analyte results in underestimated concentrations, while the generation of the analyte from a precursor or conjugate results in overestimates, and either scenario can affect case interpretation. For this reason the stability of analytes in stored samples is regarded as an essential parameter in forensic toxicology [1], and the characterisation of analyte stability in standards, quality controls and study samples is recognised as an important component of bioanalytical method validation [2]. Because almost all

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container comparisons concern cannabinoids, they are used here as a model system, and the review makes no claim of equal coverage for every class of poison.

Several processes can reduce the concentration of an analyte in a stored sample. These include conjugate formation, adsorption to container surfaces, microbial action, thermal decomposition and errors in handling [1]. The container is the one factor that the person collecting the sample chooses at the outset and cannot change afterwards, and yet it is often selected for convenience, cost or breakage resistance rather than for chemical compatibility with the suspected poison. Reviews of how to stabilise drug molecules in biological samples have long stressed that the choice of storage conditions is part of the analytical method and not a clerical detail [3]. In this article, the term poison refers to any drug, pesticide, or other toxic substance detected in a biological or exhibit sample in a medico-legal context. The objective of this work is to evaluate the existing knowledge concerning the influence of various containers, closures, and storage conditions on the stability of poisons. Particular attention is paid to identifying the areas in which reliable conclusions can be drawn. It is also aimed at summarizing the results in a set of recommendations regarding the collection, transportation, and storage conditions. The findings are grouped according to the mechanisms of loss, the properties of materials used in the manufacturing of containers, descriptions specific for each of the major sample categories, the impact of temperature and additives, and unresolved problems.

Scope and approach

This is a descriptive (narrative) review. Peer-reviewed articles were identified by searching the indexed literature and were supplemented by references in narrative reviews, and each article used was checked against the publisher's record or database entry (Sections 2.1 and 2.2). The review focused on experimental studies that directly compared standardized jars, closures, or storage circumstances, as well as reports that collate these comparisons. There were 34 sources in total. A protocol was not created, and the statistical risk-of-bias score was not estimated. The review should therefore be regarded as a structured abstract rather than an organized review with a pooled estimate; instead, the quality of the evidence is assessed qualitatively (Section 2.2). One feature of the evidence base influences everything that follows. Cannabinoids are the most interesting substances for comparison between the storage in glass and plastic as they are highly lipophilic and therefore may adhere to plastic surfaces. The evaluated sources did not include any experimental data on the comparison of the properties of storage containers for insecticides, cyanide, metallic, volatile poisons, or other traditional toxicants (Section 7 summarizes the storage-state data for ethanol and cyanide). Therefore, the results for cannabis are presented as the most extensively documented case of receptacle effects, and the migration to other toxins is assumed as an open question for further investigations.

LITERATURE SEARCH AND ELIGIBILITY CRITERIA

The reporting items of the PRISMA 2020 statement relevant to a narrative review formed the basis for the intended searches [35]. The citations which were subsequently included were published in 1984 and 2022. The integrated collection was accessed in PubMed, Scopus,, the World Wide Web for Science,, and Google Scholar to find entries created up until 2022. The procedure (adsorption, loss, extraction, stability, and storage), the material or matrix in a query (forensic toxicology, toxicology, substances of abuse, marijuana, urine, blood, a GI fluid), and container (bottle, vial, tube, plastic, glass, a styrene, a polyethylene, stopper, a closure, a label, etc.) were all searched for. The Boolean operators included words such that (bottle containing OR bottles OR tubing OR polypropylene OR glassware OR cork) Or (adsorption) OR degradation OR recovery OR endurance AND cannabinoid based OR THC OR hazardous OR toxicant AND blood OR urine OR "ingestion fluid." Records that summarized comparisons of this kind or provided analytical amounts, loss rates, or recoveries in biological or exhibit matrices that were assessed in at least three jars, closures, additions, or storage conditions were qualified. Documents that addressed non-toxicological analytes, only provided detailed information on the analytical method validation but did not present stability information, or were not entirely written in English were excluded. One phd thesis [33] was labeled as gray literature because it was the only published study on pesticides.S

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Screening, data extraction and appraisal of evidence quality

The text of all potentially eligible records was assessed against the criteria stated above following the initial screening of titles and abstracts and manual searching of references from included reviews. A flow diagram illustrating this process, created using the PRISMA software, is not presented here as there is no record of the number of documents screened at each stage, even though 34 sources met the requirements and were retained. Information extracted from each included source comprised the research structure, analyte, matrix, vessels contrasted, storage conditions, outcome metric and key findings. The quantitative results for each of these variables are presented according to the publication from which they were extracted.

A quantitative risk-of-bias score was not computed due to the sources' significant differences in analyte, matrix, container, and design.The sources were instead appraised qualitatively. Each container-related study is described in Table 2 (study characteristics) and rated A, a direct comparison of containers, closures or labels under identical conditions, or B, a storage condition, additive or single container type examined without a direct container comparator. The sample origin (spiked or authentic), the number of analytes and the main limitation of each study are also recorded. The criteria are adapted from the directness and consistency domains used to grade the certainty of evidence [36] and from the quality items proposed for narrative reviews [37]; they represent the reviewers' judgement and not a validated instrument. Replicate numbers and statistical reporting were not rated, because they were not reported in a uniform way across the sources.

Table 2. Evaluation of qualitative evidence and study features (A = straight container contrast; B = condition, beneficial, or single container; THC-COOH = 11-nor-Δ9-THC-9-carboxylic acid)

Ref.	Analyte and matrix	Comparison made	Metric as reported	Rating	Main limitation
[4]	THC-COOH, urine	PP vs borosilicate glass; urine pH; exposure time	Adsorptive loss (qualitative)	A	One metabolite; no percentages in the summary used
[5]	THC-COOH, solutions	Solution composition and container materials (HDPE poorest; glass advised)	Loss (ranking)	A	One metabolite; older study
[6]	THC-COOH, urine, 4 and 25 °C	PP vs PE	Loss: about 5% in PP and none significant in PE at 25 °C; rapid at 4 °C	A	Ranking conflicts with [11]
[7]	THC, whole blood, −20 °C, 4–24 weeks	Polystyrene vs glass	Loss: 60–100% vs 30–50%	A	Single analyte; 1986; glass also lost THC
[8]	11 synthetic cannabinoids, authentic oral fluid, 72 h	Borosilicate glass vs PP at several temperatures	Recovery: 9–54% (PP, room temp.) vs 84–114% (glass)	A	Short duration; one analyte class
[9]	Cannabinoids, ante- and postmortem blood, glass vials	Refrigerated or frozen storage, about 6 months	Loss: about 20%	B	Glass only
[10]	THC, spiked oral fluid	Fill volume in PP containers	Loss: 23–30% in 6 days	B	Spiked; one plastic

[11]	Cannabinoids, urine after controlled smoking	PP vs PE (PP preferred; glass noted)	Adsorptive loss (qualitative)	A	Qualitative; ranking conflicts with [6]
[12]	11-nor-Δ9-THC, spiked urine, 2–8 °C	HDPE only	Loss: about 11% in about 79 days	B	One plastic; contrasts with [5]
[13]	THC-COOH, urine	Internal vs external bar-code label	Loss: about 50% vs about 14%	A	Short 1990 report; label type only
[14]	THC and metabolites, blood and plasma, room temp., 6 months	Rubber-stoppered tubes	Decrease: about 90%	B	Stopper effect proposed, not isolated
[16]	THC, blood and plasma, plastic gray-top NaF tubes	Storage temperature in one tube type	Stability duration: about 1 week at room temp.; 6 months at 4 °C or −20 °C	B	One tube type; controlled-administration samples
[18]	THC, urine, Pyrex bottles, −20 °C	With vs without non-ionic surfactant	Loss: below 20% at 49 weeks vs above 20% at 21 weeks	B	Glass only; one additive
[22]	THC and related cannabinoids, whole blood, plastic containers, −20 °C	Antioxidant mixture; freeze–thaw cycles	No significant loss at 5 months with additive	B	Cannabinoids only
[23]	Synthetic cannabinoids, blood, glass vials	Storage temperature, 12 weeks	Loss: e.g. XLR-11 31–73% at 3 weeks (4 °C, room temp.)	B	Glass only; compound-specific
[25]	THC-COOH, urine, PP, −20 °C	Storage time, up to 3 years	Loss: up to 19.6 ± 6.7%	B	One container type
[28]	THC and metabolites, spiked dried blood spots	Storage time at room temp.	Loss: below 10% at 3 months	B	Spiked; not a container comparison
[33]	Drugs and pesticides, blood (doctoral thesis)	Sodium fluoride; storage conditions	Stability gain: below 10% with NaF	B	Grey literature; no plastic–glass comparison

Seven of the 18 tabulated studies compared containers or labels directly (rating A), and all seven examined cannabinoids (THC, THC-COOH or synthetic cannabinoids); the other 11 examined a storage condition, an additive or a single container type. The certainty of the evidence that plastic causes greater loss of cannabinoids than glass was judged low to moderate: the direct comparisons are few, mostly older, and limited to one analyte family, and two of them disagree on which plastic is better. The certainty for any other poison is very low, because no direct container comparison was found.

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Terminology

The following terms are used consistently. Adsorption is the binding of an analyte to the surface of a container, closure or label; absorption is the partitioning of an analyte into the bulk of a polymer; loss is the decrease in measured concentration relative to the initial concentration, expressed as a percentage; recovery is the measured concentration expressed as a percentage of the initial (or nominal) concentration, so that recovery equals 100% minus loss for the same sample; and stability means that the concentration stayed within a pre-defined acceptance limit of the initial value [38]. Percentages are quoted as each source reported them; loss and recovery are not converted into one another or pooled across studies.

Why stored samples change

The factors that decide what a stored sample still contains fall into four groups, shown in Figure 1. The first type of determinants is the molecule's composition: conjugates such as glucuronides, for instance, may hydrolyze back to their previous forms, lipophilic compounds adhere easily to the surfaces made of lipophilic plastic, and thermally or chemically volatile compounds decompose over time. The second one is associated with the matrix's lifespan: the pH of the urine influences the ability of a molecule to adhere to the surface, serum contains enzymes named ethyl esterase that target fragile substances, and microorganisms and fungi development may alter or consume analytes at elevated temperatures [1, 4]. The third group is the container (wall material, closure, label and surface-to-volume ratio) and the fourth is handling (temperature, freeze-thaw cycles, preservatives and storage time); both are examined in Sections 4 to 6.

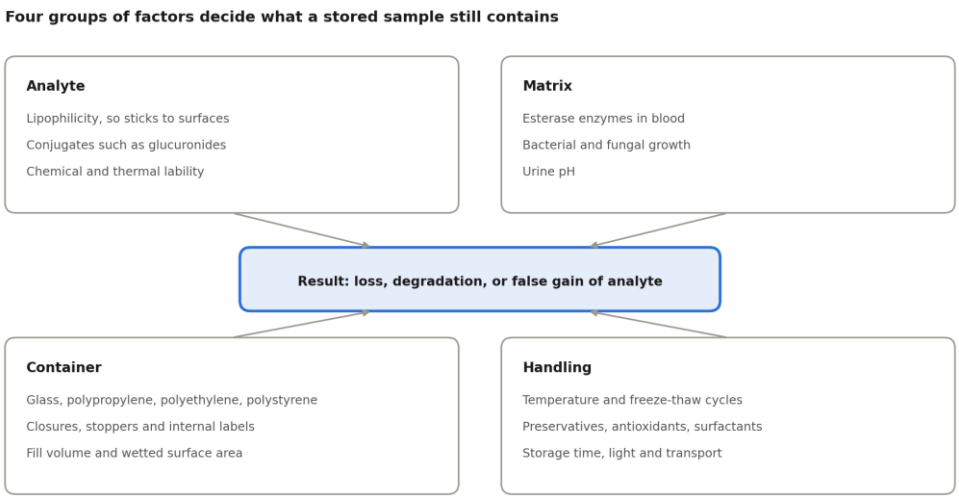


Figure 1. Factors that determine the stability of an analyte in a stored sample.

The nature of the loss to plastic has also been clarified. When urine containing the carboxylic acid metabolite of THC was kept in polypropylene and polyethylene at 4 °C and 25 °C, the reduction level stabilized after about an hour, leading the authors to conclude it was a surface phenomenon (adsorption) and not absorption into the plastic structure [6]. This is important for solutions because a surface effect can potentially be reduced by changing the surface, the solvent, or the surface-to-volume ratio, whereas bulk absorption cannot be altered; this practical implication is an inference from the mechanism and is not a tested result.

Container materials and closures

Glass

Glass has repeatedly been the container in which the best recoveries were obtained for cannabinoids, although its inertness is conditional, as qualified below. In whole blood stored at −20 °C for 4 to 24 weeks, THC losses were 30 to 50% in glass vials compared with 60 to 100% in polystyrene [7]; even the lower figure shows that glass does not prevent loss. Borosilicate glass tubes gave recoveries of 84 to 114% for 11 synthetic cannabinoids

in oral fluid across all temperatures over 72 h, whereas polypropylene tubes gave far lower recoveries (9 to 54%) at room temperature [8]. Blood data are expressed as loss and oral fluid data as recovery, so the two sets of figures should not be compared directly. In urine, adsorptive loss of the THC carboxylic acid metabolite was marked in polypropylene but relatively absent in borosilicate glass [4], and a study of solution composition and container material advised glass containers for storage and glass pipettes for handling [5].

Glass has its own drawbacks. Breakage is a practical hazard in transport and in the field, and this is one reason glass vials are often disfavoured for routine storage of biological matrices even where they perform best chemically [1]. Glass is also not a guarantee of stability, because analytes can still degrade chemically or enzymatically; in whole blood in glass vials, cannabinoids kept refrigerated or frozen remained stable for about six months although about 20% of their initial concentration was lost [9].

The statement that glass is inert therefore needs qualification by glass type, analyte, matrix and closure. Borosilicate glass carries surface silanol groups whose abundance varies with the glass quality, and basic analytes can bind to them ionically, with losses that are time-dependent and greater at low concentrations [39, 40]. The same technical sources describe hydrophobic adsorption to both glass and polypropylene, so lipophilic analytes are not exempt from loss to glass [39]. These sources are manufacturers' technical documents on chromatography vials and basic drugs, not peer-reviewed forensic storage studies, and they are cited only to show that the inertness of glass cannot be assumed; the effect of glass type on cannabinoids stored in blood, urine or oral fluid was not examined in the sources reviewed. Closures add a further variable, because the stopper or cap liner is usually not glass (Section 4.3). Therefore, glass jars ought to have been validated for the specific analyte as should plastic containers.

Plastics

Plastic bottles are more common and lighter, less expensive and safer to handle, but not convertible.Polystyrene performed worst in the blood comparison noted above [7]. Polypropylene showed marked adsorptive loss of lipophilic drugs in oral fluid at room temperature, and the study that documented this advised that samples held in polypropylene tubes be shipped cooled [8]. Lower oral fluid volumes led to greater adsorptive loss of THC in polypropylene, consistent with a surface effect, and THC loss reached 23 to 30% within 6 days and 40 to 50% over 4 weeks [10, 1].

The evidence on which plastic is best is mixed, and this should be acknowledged openly. In one urine study, polypropylene was preferred over polyethylene because it appeared to cause less adsorptive loss, although the authors also noted that glass avoided adsorption entirely at the price of breakability [11]. In another study at 25 °C there was no significant loss of the THC carboxylic acid metabolite in polyethylene and a small loss of about 5% in polypropylene, while at 4 °C both lost the compound rapidly [6]. High-density polyethylene held spiked urine at 2 to 8 °C with only about 11% loss over roughly 79 days [12], yet it gave the poorest results in a study comparing materials and solutions [5]. A plausible interpretation is that a material should be tested for the specific toxin rather than being presumed safe, and that plastics grading is based on analyte, matrix, temperature, and duration.

Closures, stoppers, labels and tube additives

The parts of a container other than its walls can matter as much as the walls. Whole blood containing cannabinoids stored in tubes with rubber stoppers for 6 months at room temperature lost about 90% of the analytes, and the authors raised the possibility of loss to the rubber stoppers [14, 1]. Internal bar-code labels offer a striking example: urine containing the THC carboxylic acid metabolite lost about 50% in bottles with internal bar-code labels against about 14% in the same bottles with external labels, an effect attributed to the waterproof polypropylene of the internal label [13].

Blood collection tubes also contain anticoagulants and preservatives, and the type chosen influences stability. The importance of selecting the right vacutainer for forensic analysis of drugs of abuse has been stressed in the literature [17]. In plastic gray-top sodium fluoride tubes, THC in blood was stable for about one week at room temperature and for 6 months when kept at 4 °C or −20 °C, while the glucuronide of the carboxylic acid

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metabolite was stable for less than a week at room temperature [16]. Sodium heparin tubes behaved similarly for several analytes [15]. Table 1 collects the container effects reported across the sources reviewed, and Table 2 (Section 2.2) rates the strength of that evidence.

Table 1. Container effects reported in the reviewed studies

Container or component	Matrix and analyte	Reported effect	Source
Borosilicate glass	Oral fluid, 11 synthetic cannabinoids, 72 h	Recovery 84–114% at all temperatures tested	Kneisel et al. [8]
Polypropylene	Same samples	Recovery 9–54% at room temperature and 75–79% at 4 °C after 72 h	Kneisel et al. [8]
Polystyrene versus glass	Whole blood, THC, −20 °C, 4–24 weeks	Loss 60–100% in polystyrene against 30–50% in glass	Christophersen [7]
Polypropylene versus borosilicate	Urine, THC carboxylic acid metabolite	Adsorptive loss is considerable in polypropylene and comparatively low at neutral or basic pH.	Jamerson et al. [4]
Polypropylene and polyethylene	Urine, THC carboxylic acid metabolite, 4 °C and 25 °C	Both lose quickly at 4 degrees Celsius; at 25 °C, polypropylene loses roughly 5% while polyethylene loses nothing.	Stout et al. [6]
High-density polyethylene	Urine, THC, 2–8 °C	About 11% loss over roughly 79 days	Giardino [12]
Polypropylene container	Urine, THC carboxylic acid metabolite, −20 °C	Maximum loss 19.6 ± 6.7% over 3 years	Fraga et al. [25]
Internal bar-code label	Urine, THC carboxylic acid metabolite	About 50% loss against about 14% with external label	Bond et al. [13]
Rubber-stoppered tubes	Whole blood, cannabinoids, room temperature, 6 months	About 90% decrease	Johnson et al. [14]
Plastic gray-top sodium fluoride tubes	Whole blood, THC	Stable about 1 week at room temperature; 6 months at 4 °C and −20 °C	Scheidweiler et al. [16]

Note: values are given as each source reported them. Loss and recovery are not interchangeable and were not converted between rows (see Section 2.3).

Evidence by sample type

Blood and plasma

In blood and plasma, temperature is the first determinant of stability, and the container is the second. Cannabinoid concentrations in blood fall significantly after 2 weeks to 2 months at room temperature regardless of container material, whereas frozen or at least refrigerated storage preserves them far longer [14, 1]. The choice of tube and preservative alters the picture further, and enzymatic activity is an independent threat. The glucuronide of the carboxylic acid metabolite degrades in blood and plasma, and susceptibility to esterase enzymes naturally present in blood has been proposed as the reason [17, 15].

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue X O October 2026

Synthetic cannabinoids add compound-specific behaviour. In glass vials, AB-FUBINACA, AB-PINACA and UR-144 in blood remained stable for 12 weeks at all three temperatures tested, whereas XLR-11 was lost by 31 to 73% after 3 weeks and by 70 to 90% after 12 weeks at 4 °C and room temperature, although all were stable when frozen [23]. Repeated freezing and thawing of serum in glass tubes did not significantly lower concentrations of many synthetic cannabinoids [21], but in whole blood stored in plastic containers at −20 °C a significant difference appeared between samples frozen continuously and those that had undergone freeze-thaw cycles [22].

Urine

Urine is the most widely used matrix for drug testing, and its stability depends on pH, storage temperature, bacterial contamination and the container material [1]. Frozen storage was again the most favourable: recovery of THC-related analytes was about 85% after 20 weeks at −20 °C against 37% and 33% at 4 °C and 25 °C [26], and the carboxylic acid metabolite lost no more than 19.6 ± 6.7% over 3 years frozen in polypropylene [25]. The free and glucuronidated forms of the metabolite behave differently, and a study of authentic urine samples examined their stability over time [24].

pH emerges as an important modifier of container effects. Adsorptive loss of the carboxylic acid metabolite was relatively absent in urine at near neutral or basic pH [4]. Treating urine with a non-ionic surfactant also helped: in Pyrex bottles at −20 °C, losses were below 20% after 49 weeks with the surfactant against more than 20% after 21 weeks without it [18]. Microbial growth is a further factor, but it appears to matter only when the temperature is high enough to allow bacteria and fungi to grow [27].

Oral fluid

Oral fluid is attractive for roadside testing, and it is also the matrix in which container effects are most dramatic because collection devices are typically plastic. Recoveries of 11 synthetic cannabinoids fell to 29 to 65% after 24 h and 9 to 54% after 72 h in polypropylene at room temperature, but remained 83 to 103% at 24 h and 75 to 79% at 72 h at 4 °C, and stayed 84 to 114% in borosilicate glass under all conditions tested [8]. THC behaved similarly, with 23 to 30% adsorptive loss in polypropylene within 6 days and greater loss at lower volumes [10]. The synthetic cannabinoid data are expressed as recovery and the THC data as loss, so the two should not be compared directly (Figure 2). A study of the Quantisal collection device concluded that samples should not contact plastic surfaces, should be frozen or refrigerated and should be kept in the dark [19], and the effect of the collection procedure on results has been described as a neglected variable in oral fluid testing [20].

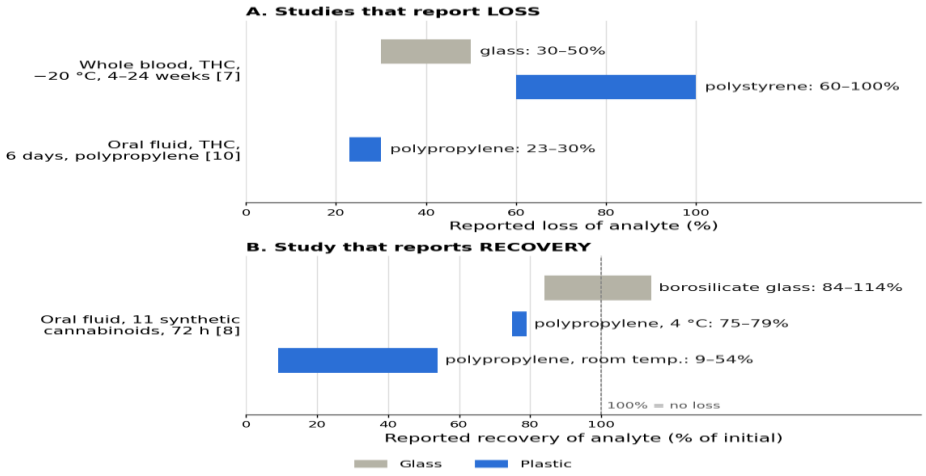


Figure 2. Container effects on cannabinoid analytes as originally reported. Panel A shows loss (%) in whole blood [7] and oral fluid [10]; panel B shows recovery (% of the initial concentration) of 11 synthetic cannabinoids in oral fluid after 72 h [8], where values near 100% indicate no loss. Loss and recovery were not converted into one another, the ranges come from separate studies with different analytes, matrices and conditions, and bars should be compared only within a row. Glass is shown in grey and plastic in blue.

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue X O October 2026

Dried blood spots as a container-light alternative

Dried blood spots avoid most of the liquid-phase problems described above. THC and its main metabolites in blank spiked spots stored at room temperature for 1 week, 1 month or 3 months showed minimal differences, with loss below 10% even after 3 months, and the authors attributed this to the absence of enzymatic processes in dried spots [28]. Other work found stability within ±10% over 30 days at room temperature and no relevant instability for two weeks [29, 30]. Cannabinoids are among the harder analytes to detect in such spots because they leave the blood quickly, so a positive result points to recent intake, and the method is better regarded as a complement to conventional sampling than a replacement [32].

Temperature, preservatives and other modifiers

Across matrices, cold is the most consistent protective measure. Storing blood, urine or oral fluid frozen, or refrigerated at the least, repeatedly gave the best stability, and the advantage held in glass and in plastic, even though the container effect remained [1]. The practical conclusion is that a poor container can sometimes be partly compensated by low temperature, but a good container does not compensate for storage at room temperature.

Chemical additives can improve stability. A mixture of fluoride oxalate and ascorbic acid prevented significant cannabinoid loss in whole blood after 5 months even when storage was interrupted by six freeze-thaw cycles [22]. A non-ionic surfactant raised THC recovery from urine in Pyrex bottles [18], and the authors of a major review recommended that blood and plasma be collected into glass or at least into plastic containing stabilising agents such as antioxidants [1]. Preservatives are not uniformly effective, however. A doctoral study of drugs and pesticides in blood under different storage conditions reported that sodium fluoride produced less than a 10% increase in stability for the compounds studied [33]. Any preservative should therefore be tested against the analytes of interest. The additive findings above come from cannabinoids in blood and urine and should not be extended to other analytes or matrices without testing.

Beyond cannabinoids: poisons that remain under-studied

The container literature reviewed here rests heavily on cannabinoids, and the question is how far it applies to other poisons. Since adsorption of lipophilic compounds onto plastic is common physicochemical process, it is easy to assume that other highly lipophilic toxins will display similar behaviour. However, it is a speculation and was not applied for the poisons mentioned below. The mentioned sources do not discuss any comparisons with ionic or hydrophobic poisons, minerals that would dissolve or leach from the capsule's exterior, and volatiles that could be lost to the atmosphere or even the seals. The nearest container-related evidence outside the cannabinoids concerns ethanol, a volatile compound. The ethanol concentration declined with storage time in blood from drivers who were intoxicated obtained into ventilated glass tubes filled with potassium oxalate and sodium fluoride and stored at 4 °C. This decrease was 0.217 ± 0.054 mg/g in tubing reopened on 17 occasions over 6.5 months, compared to 0.101 ± 0.076 mg/g in trays kept unopened [41]. This implies that the headspace and closure, instead of wall material, are the vital vessel variables for volatile analytes. However, as the study did not compare glass and plastic, it must only be read as a closure effect on ethanol.

Cyanide shows how strongly analyte chemistry can dominate. Cyanide is volatile and reactive, and in postmortem pig blood its half-life was 10.7 h at 25 °C and 6.6 h at 37 °C, whereas the metabolite 2-aminothiazoline-4-carboxylic acid was far more stable [42]. Dedicated reviews of cyanide stability in human samples are available [43, 44]. Container material was not the variable examined in the cyanide study cited here [42], and no glass-versus-plastic comparison for cyanide was identified in the sources examined for this review, so the contribution of the container cannot be separated from temperature, time and matrix effects.

For pesticides, the only source identified was a doctoral thesis on the stability of drugs and pesticides in blood under different storage conditions [33], in which sodium fluoride produced less than a 10% increase in stability for the compounds studied; it did not provide a systematic comparison of plastic and glass for major pesticide classes. No container comparison was identified for metals either. Testing of the possible interactions of containers, preservatives, pH, and heat for each class of toxin is a priority since the recommendations on these

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hazardous chemicals may not be determined based on the evidence currently available (Section 9). The claims in Section 8 are limited to the considerations of Table 3, which distinguishes the evidence originating from the mentioned sources and extrapolated or hypothetical.

Table 3. Status of the main statements made in this review

Status	Statement	Basis
Constant across probes	Studies have shown that silica is more effective in preserving THC, TC-COOH, and synthetic cannabis metabolites in biological fluids than other media such as polystyrene and polypropylene.	[4, 5, 7, 8]
Consistent across studies	Cold storage is better for preserving cannabinoids in plastic and glass than room temperature storage.	[1, 14, 26]
Conflicting	Which is superior, high density polyethylene or polypropylene polyethylene?	[5, 6, 11, 12]
Single study	Major losses with rubber sealed packaging (blood cannabinoids) and inside-out bar-code labels (urine THC-COOH)	[13, 14]
Single study	A non-ionic surfactant in urine, or fluoride oxalate with ascorbic acid in blood, limits THC loss	[18, 22]
Mechanistic hypothesis	Loss to plastic is a surface effect and might be reduced by changing the surface, solvent or surface-to-volume ratio	[6]; practical implication untested
Mechanistic hypothesis	Esterase activity explains degradation of the THC-COOH glucuronide in blood and plasma	[15, 17] (described as proposed)
Outside forensic storage studies	Glass is not universally inert: silanol groups bind basic analytes and glass quality matters	[39, 40] (technical documents)
Extrapolation (untested)	Other highly lipophilic poisons behave like cannabinoids in plastic containers	No study identified
Extrapolation (untested)	Antioxidants, surfactants or fluoride protect analytes other than cannabinoids	Sodium fluoride gave under 10% gain in [33]
Extrapolation (untested)	Glass is the safer container for pesticides, metals, cyanide and volatile poisons	No container comparison found; closure effect on ethanol only [41]

Practical guidance

The evidence supports a small set of practical rules, summarised as a workflow in Figure 3, each of which is limited to the analytes and matrices in which it was tested (Table 3). For lipophilic cannabinoids in blood, urine and oral fluid, glass was associated with the best recoveries and should be preferred where its breakage risk can be managed, and any plastic used should be shown to give acceptable recovery for the suspected poison under the expected storage time and temperature. Closures, rubber stoppers and internal labels should be checked, because they were associated with large losses in the studies reviewed [13, 14]. Ascorbic acid added with oxalate was tested in the whole blood for both cannabinoids [22] and a surfactant that is not ionic in urine to test for THC [18], with consideration given to pH of urine [4]. No data supports routinely giving these additives for

other substances, and sodium fluoride alone failed to assist each compound [33]. Additives for stabilization should only be used if established for the reagent and matrix. To minimize the number of freeze-thaw cycles, the samples should be rapidly frozen/relocated to a refrigerator, transported cold, and tested. These recommendations are conservative defaults before packaging- and test-specific stability has been established; they are not recommendations for toxins beyond the cannabis category.

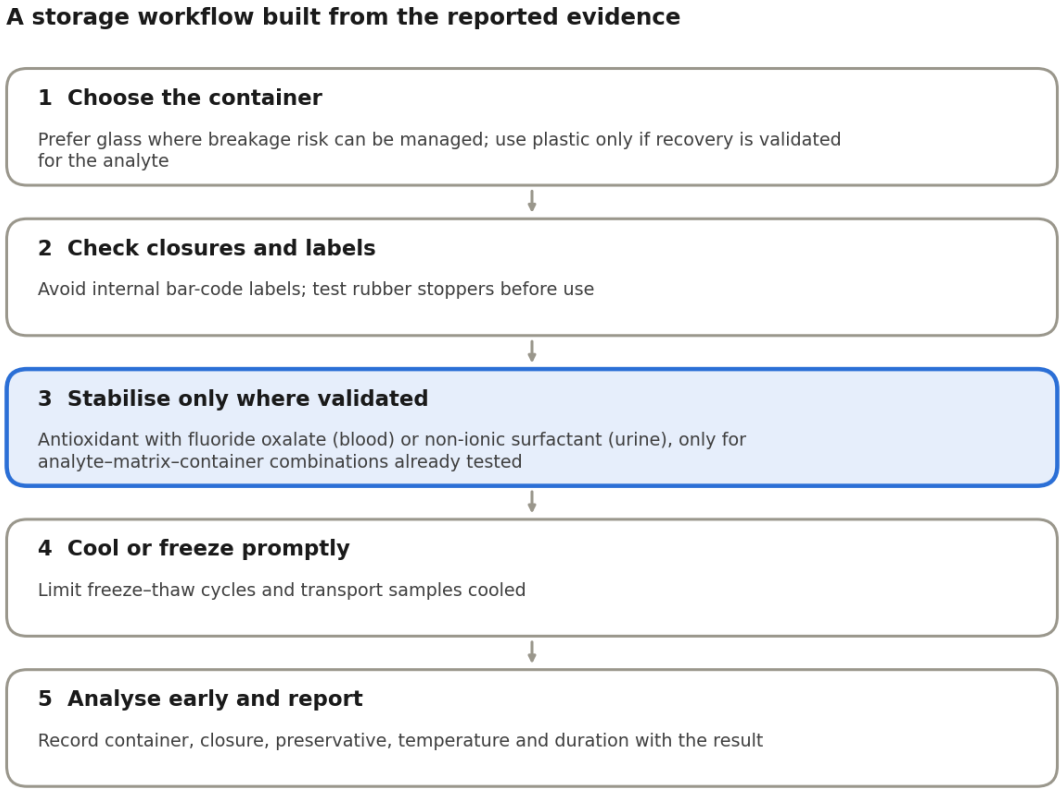


Figure 3. A storage workflow derived from the reported evidence. Each step applies only to analyte–matrix–container combinations in which it has been tested; for other poisons the steps are precautionary defaults. The container and closure checks in steps 1 and 2 cannot be corrected after collection.

Laboratories should also record the container type, closure, preservative, storage temperature and duration with every result, so that a concentration can be interpreted in the light of how it was held. Where a sample has been stored in a container known or suspected to cause adsorptive loss, the reported concentration should be regarded as a minimum estimate for lipophilic analytes (an interpretive rule, not a validated correction factor). Method validation should include storage stability in the actual collection container, not only in the glassware used on the bench, since a stability study run in glass says little about the same compound in a polypropylene tube [2, 8, 38].

Gaps and research priorities

There are few apparent gaps. First, common toxins such as metals, chlorine, organophosphate, and carbamate-based insecticides, and volatile compounds including closure-related losses, require comparison with the same criteria as for cannabis using container comparisons. Second, factorial designs that examine interactions would be more informative since typical studies evaluate a single variable, such as one container, one temperature or one preservation agent, whereas practice combines all three. Third, the inconsistent ranking of polypropylene and polyethylene suggests that results are not generalizable across analyte, matrix or laboratory, and that matched, multiple analyte comparisons are required. Fourth, the quantitative loss in postmortem samples, which have a different protein, lipid and microbial profile to antemortem samples, requires a dedicated investigation. Fifth, studies should report the surface area to volume ratio and fill volume, as both will influence adsorptive loss. Finally, a protocol-based systematic review with formal risk-of-bias assessment [35] will become possible once enough comparable studies exist for poisons other than cannabinoids.

CONCLUSIONS

Instead of being a passive vessel, the container actively contributes to the stable condition of a sample that is being stored. After days or weeks, sorption onto plastic substrates may cause a massive loss of the analyte for cannabis, the most well-studied model of lipophilic medicines. The recovery of 11 artificial cannabinoids in oral fluids at ambient temperature was 9 to 54% in polypropylene and 84 to 114% in glass with borosilicates, and THC losses in frozen whole blood had been 60 to 100% in polystyrene, contrasted with 30 to 50% in glass, while (loss and recovery rate are given as stated in the initial studies). Temperature, pH, anticoagulants, antioxidants, surfactants, stoppers, closures, even interior labels can impact results. Additionally, the evidence has definite limitations: It was rated as low to medium certainty, is primarily based on cannabinoids, is based on just a handful of generally older research (Table 2), and studies' rankings of plastics vary, not all analytes benefit from preservatives such sodium fluoride, and the literature reviewed did not include vessel evaluations for pesticides, cyanide, metals, and volatile toxins. Therefore, conclusions on cannabinoids should not be considered as evidence that other poisons act via the same mechanisms, but rather as a guide. There are three useful lessons here. When cannabis compounds are the analytes of interest, collectors should use glassware or containers that have been demonstrated to exhibit low adsorption; the sample should be quickly frozen or chilled; unproven inner-label or sealing techniques should be avoided; in addition, labs should log storage conditions and test for stability in the specific container used. Investigators should use designs that simultaneously evaluate containers, preservation, and temperature to further studies on the traditional toxin that dominates the medico-legal casework. If those conditions were met, the amount of stored specimens would be more precise as proof.

REFERENCES

1. Djilali E, Pappalardo L, Posadino AM, Giordo R, Pintus G. Effects of the storage conditions on the stability of natural and synthetic cannabis in biological matrices for forensic toxicology analysis: an update from the literature. Metabolites. 2022;12(9):801. doi:10.3390/metabo12090801
2. Nowatzke W, Woolf E. Best practices during bioanalytical method validation for the characterization of assay reagents and the evaluation of analyte stability in assay standards, quality controls, and study samples. AAPS J. 2007;9(2):E117-E122. doi:10.1208/aapsj0902013
3. Chen J, Hsieh Y. Stabilizing drug molecules in biological samples. Ther Drug Monit. 2005;27:617-624. doi:10.1097/01.ftd.0000170879.18139.40
4. Jamerson MH, McCue JJ, Klette K. Urine pH, container composition, and exposure time influence adsorptive loss of 11-nor-Δ9-tetrahydrocannabinol-9-carboxylic acid. J Anal Toxicol. 2005;29:627-631. doi:10.1093/jat/29.7.627
5. Roth KD, Siegel NA, Johnson RW Jr, Litauszki L, Salvati L Jr, Harrington CA, et al. Investigation of the effects of solution composition and container material type on the loss of 11-nor-Δ9-THC-9-carboxylic acid. J Anal Toxicol. 1996;20:291-300. doi:10.1093/jat/20.5.291
6. Stout PR, Horn CK, Lesser DR. Loss of THCCOOH from urine specimens stored in polypropylene and polyethylene containers at different temperatures. J Anal Toxicol. 2000;24:567-571. doi:10.1093/jat/24.7.567
7. Christophersen AS. Tetrahydrocannabinol stability in whole blood: plastic versus glass containers. J Anal Toxicol. 1986;10(4):129-131. doi:10.1093/jat/10.4.129
8. Kneisel S, Speck M, Moosmann B, Auwärter V. Stability of 11 prevalent synthetic cannabinoids in authentic neat oral fluid samples: glass versus polypropylene containers at different temperatures. Drug Test Anal. 2013;5:602-606. doi:10.1002/dta.1497
9. Meneses V, Mata D. Cannabinoid stability in antemortem and postmortem blood. J Anal Toxicol. 2019;44:126-132. doi:10.1093/jat/bkz073
10. Molnar A, Lewis J, Fu S. Recovery of spiked Δ9-tetrahydrocannabinol in oral fluid from polypropylene containers. Forensic Sci Int. 2013;227:69-73. doi:10.1016/j.forsciint.2012.11.006
11. Desrosiers NA, Lee D, Scheidweiler KB, Concheiro-Guisan M, Gorelick DA, Huestis MA. In vitro stability of free and glucuronidated cannabinoids in urine following controlled smoked cannabis. Anal Bioanal Chem. 2014;406:785-792. doi:10.1007/s00216-013-7524-7
12. Giardino NJ. Stability of 11-nor-Δ9-tetrahydrocannabinol in negative human urine in high-density polyethylene (Nalgene). J Anal Toxicol. 1996;20:275-276. doi:10.1093/jat/20.4.275

13. Bond GD 2nd, Chand P, Walia AS, Liu RH. Observation of reduced concentration of Δ9-THC-carboxylic acid in urine specimen containers using internal barcode labels. J Anal Toxicol. 1990;14:389-390.
14. Johnson JR, Jennison TA, Peat MA, Foltz RL. Stability of Δ9-tetrahydrocannabinol (THC), 11-hydroxy-THC, and 11-nor-9-carboxy-THC in blood and plasma. J Anal Toxicol. 1984;8:202-204. doi:10.1093/jat/8.5.202
15. Scheidweiler KB, Schwope DM, Karschner EL, Desrosiers NA, Gorelick DA, Huestis MA. In vitro stability of free and glucuronidated cannabinoids in blood and plasma following controlled smoked cannabis. Clin Chem. 2013;59:1108-1117. doi:10.1373/clinchem.2012.201467
16. Scheidweiler KB, Himes SK, Desrosiers NA, Huestis MA. In vitro stability of free and glucuronidated cannabinoids in blood and plasma collected in plastic gray-top sodium fluoride tubes following controlled smoked cannabis. Forensic Toxicol. 2016;34:179-185. doi:10.1007/s11419-015-0290-9
17. Toennes SW, Kauert GF. Importance of vacutainer selection in forensic toxicological analysis of drugs of abuse. J Anal Toxicol. 2001;25:339-343. doi:10.1093/jat/25.5.339
18. Welsh ER, Snyder JJ, Klette KL. Stabilization of urinary THC solutions with a simple non-ionic surfactant. J Anal Toxicol. 2009;33:51-55. doi:10.1093/jat/33.1.51
19. Moore C, Vincent M, Rana S, Coulter C, Agrawal A, Soares J. Stability of Δ9-tetrahydrocannabinol (THC) in oral fluid using the Quantisal collection device. Forensic Sci Int. 2006;164:126-130. doi:10.1016/j.forsciint.2005.12.011
20. Crouch D. Oral fluid collection: the neglected variable in oral fluid testing. Forensic Sci Int. 2005;150:165-173. doi:10.1016/j.forsciint.2005.02.028
21. Hess C, Krueger L, Unger M, Madea B. Freeze-thaw stability and long-term stability of 84 synthetic cannabinoids in serum. Drug Test Anal. 2017;9:1506-1511. doi:10.1002/dta.2133
22. Sørensen LK, Hasselstrøm JB. The effect of antioxidants on the long-term stability of THC and related cannabinoids in sampled whole blood. Drug Test Anal. 2018;10:301-309. doi:10.1002/dta.2221
23. Fort C, Jourdan T, Kemp J, Curtis B. Stability of synthetic cannabinoids in biological specimens: analysis through liquid chromatography tandem mass spectrometry. J Anal Toxicol. 2017;41:360-366. doi:10.1093/jat/bkx015
24. Skopp G, Pötsch L. An investigation of the stability of free and glucuronidated 11-nor-Δ9-tetrahydrocannabinol-9-carboxylic acid in authentic urine samples. J Anal Toxicol. 2004;28:35-40. doi:10.1093/jat/28.1.35
25. Fraga SG, Estévez JD, Romero CD. Stability of cannabinoids in urine in three storage temperatures. Ann Clin Lab Sci. 1998;28:160-162.
26. Ciuti R, Quercioli M, Borsotti M. Drug of abuse stability in native urine specimens vs. stabilized urine samples. Biochim Clin. 2014;38:103-109.
27. White RM. Instability and poor recovery of cannabinoids in urine, oral fluid, and hair. Forensic Sci Rev. 2018;30:33-49.
28. Mercolini L, Mandrioli R, Sorella V, Somaini L, Giocondi D, Serpelloni G, et al. Dried blood spots: liquid chromatography-mass spectrometry analysis of Δ9-tetrahydrocannabinol and its main metabolites. J Chromatogr A. 2013;1271:33-40. doi:10.1016/j.chroma.2012.11.030
29. Protti M, Rudge J, Sberna AE, Gerra G, Mercolini L. Dried haematic microsamples and LC-MS/MS for the analysis of natural and synthetic cannabinoids. J Chromatogr B. 2017;1044:77-86. doi:10.1016/j.jchromb.2016.12.038
30. Kyriakou C, Marchei E, Scaravelli G, García-Algar O, Supervía A, Graziano S. Identification and quantification of psychoactive drugs in whole blood using dried blood spot (DBS) by ultra-performance liquid chromatography tandem mass spectrometry. J Pharm Biomed Anal. 2016;128:53-60. doi:10.1016/j.jpba.2016.05.011
31. Lee D, Huestis MA. Current knowledge on cannabinoids in oral fluid. Drug Test Anal. 2014;6:88-111. doi:10.1002/dta.1514
32. Karschner EL, Swortwood-Gates MJ, Huestis MA. Identifying and quantifying cannabinoids in biological matrices in the medical and legal cannabis era. Clin Chem. 2020;66:888-914. doi:10.1093/clinchem/hvaa113
33. Alfazil AA. Stability of drugs and pesticides of forensic toxicological interest and their metabolites in biological samples [PhD thesis]. Glasgow: University of Glasgow; 2009.

34. Choi H, Baeck S, Kim E, Lee S, Jang M, Lee J, et al. Analysis of cannabis in oral fluid specimens by GC-MS with automatic SPE. Sci Justice. 2009;49:242-246. doi:10.1016/j.scijus.2009.09.015
35. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ. 2021;372:n71. doi:10.1136/bmj.n71
36. Guyatt GH, Oxman AD, Vist GE, Kunz R, Falck-Ytter Y, Alonso-Coello P, et al. GRADE: an emerging consensus on rating quality of evidence and strength of recommendations. BMJ. 2008;336:924-926. doi:10.1136/bmj.39489.470347.AD
37. Baethge C, Goldbeck-Wood S, Mertens S. SANRA—a scale for the quality assessment of narrative review articles. Res Integr Peer Rev. 2019;4:5. doi:10.1186/s41073-019-0064-8
38. Peters FT, Drummer OH, Musshoff F. Validation of new methods. Forensic Sci Int. 2007;165:216-224. doi:10.1016/j.forsciint.2006.05.021
39. Murakoshi M, Fukuzawa K, Sato Y, Asakawa N. Adsorption phenomenon and development of low adsorption vials for LC and LC/MS [technical poster]. Shimadzu Corporation. Available from: https://lcms.labrulez.com/paper/11001 (accessed 21 October 2026).
40. Thermo Fisher Scientific. Vial glass quality [technical white paper WP21833]. Available from: https://assets.thermofisher.com/TFS-Assets/CMD/Reference-Materials/wp-21833-ccs-vial-glass-quality-wp21833-en.pdf (accessed 21 October 2026).
41. Jones AW. Are changes in blood-ethanol concentration during storage analytically significant? Importance of method imprecision. Clin Chem Lab Med. 2007;45:1299-1304. doi:10.1515/CCLM.2007.289
42. Alluhayb AH, Severance C, Hendry-Hofer T, Bebarta VS, Logue BA. Can the cyanide metabolite, 2-aminothiazoline-4-carboxylic acid, be used for forensic verification of cyanide poisoning? Forensic Toxicol. 2024;42(2):221-231. doi:10.1007/s11419-024-00690-4
43. Tusiewicz K, Wachełko O, Zawadzki M, Szpot P. The stability of cyanide in human biological samples. A systematic review, meta-analysis and determination of cyanide (GC-QqQ-MS/MS) in an authentic casework 7 years after fatal intoxication. Toxicol Mech Methods. 2024;34(3):271-282. doi:10.1080/15376516.2023.2280212
44. McAllister JL, Roby RJ, Levine B, Purser D. Stability of cyanide in cadavers and in postmortem stored tissue specimens: a review. J Anal Toxicol. 2008;32(8):612-620. doi:10.1093/jat/32.8.612