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Research article

Substances of health concern in home-distilled and commercial alcohols from Texas

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ABSTRACT

Objective: Poor distillation practices in the production of spirits have historically resulted in many instances of adverse health outcomes including death. Concern has focused on lead and copper contamination as well as unhealthy levels of methanol and glyphosate. This study assesses home-distilled and commercially distilled alcohols from Texas for these substances of concern, highlighting their potential risks to public health.
Methods: Atomic absorption spectroscopy, gas chromatography, and enzyme-linked immunosorbent assay were employed to determine lead and copper, methanol, and glyphosate levels in 12 commercial and 36 home-distilled alcohol samples.
Results: Our findings showed that 11 % of the home-distilled alcohols exceeded the U.S. Alcohol and Tobacco Tax and Trade Bureau's copper safety limits of 0.5 mg/L for wine. Additionally, 36 % of these samples surpassed the European Commission (EC)'s lead legal threshold of 0.15 mg/L set for wine products. Results from commercial alcohols indicated that no samples exceeded the same safety limits for copper, and 33 % exceeded the same legal threshold for lead. Both commercial and home-distilled alcohols exhibited methanol concentrations remarkably below the 0.35 % limit for brandy set by the U.S. Food and Drug Administration. Only two home-distilled samples contained detectable glyphosate concentrations well below 100 μg/L, the maximum residue level in beer and wine established by the EC.
Conclusions: Our findings suggested that consumption of alcohol in Texas may pose potential health risks associated with the elevated content of lead and copper. There is a need for increased focus on alcohol as a potential source of exposure to heavy metals.

1. Introduction

Home-distilled alcohol (moonshine) is an unregulated distilled spirit that has been made illegally in the United States of America since 1791 when the Whiskey Tax was placed on the sale of all alcoholic beverages [1]. The illegal production of home-distilled alcohol has been linked to several major health incidences in United States (US) history and around the world [2–5]. Mosha et al. found that there were high levels of chemicals including methanol, butanol, propanol, esters, and heavy metals in home distilled alcohols in Africa

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[6]. Similarly, many studies reported hazardous contaminants in moonshine globally [7–12].

1.1. Lead and copper

Lead has been found in the US home-distilled alcohol in previous studies [7,8]. For example, Gerhardt et al. found elevated levels of lead in 58.3 % of the moonshine samples analyzed [13]. The origin of lead in home-distilled alcohol comes from two sources, the water used to make the fermented mash and the use of lead soft solders, which can contain both lead and tin [6]. Tam and Elefsiniotis showed that the leaching of lead is affected by pH and alkalinity, specifically at a neutral pH with increased alkalinity [14]. Finkelstein et al. revealed that lead accumulation in the body can damage the blood-brain barrier via the uptake of lead into endothelial cells [15]. Lead was also found to interfere with neurotransmitter systems, such as acetylcholinesterase, by putting additional stress on the system leading to cognitive issues such as poor memory or retention of new information [16]. The accumulation of lead in the bloodstream is associated with chronic renal failure [17]. In the United States, there are records of patients with elevated blood lead levels [7,18,19] and deaths [20] from home-distilled alcohol consumption. There is no specified maximum amount of lead in distilled spirits in the United States, however, there is a set limit of 0.015 mg/L on the concentration of lead in drinking water [21]. In the European Union, the recommended level of lead in wine is 0.15 mg/kg, while distilled spirits do not have a designated limit [22]. China has a threshold of 0.5 mg/kg for lead in spirits [23].

Copper is another contaminant that can be introduced into home-distilled alcohol during the distillation process [24,25]. Excess consumption of alcohol that contains copper can lead to adverse health effects including but not limited to renal failure, Wilson's Disease, and neurological damage [26]. Copper piping and/or fittings are often used in distillation apparatuses and are subject to corrosion from high temperatures and pH. The distillation process requires temperatures high enough to boil ethanol at 78.37 °C [27], exceeding the 60 °C threshold at which copper wire corrosion accelerates, resulting in copper leaching into the solution [28]. Boulay and Edwards showed that higher temperatures increased the amount of copper released into solution from copper pipes [29]. In addition, exposure to low to neutral pH and high alkalinity promoted the leaching of copper from brass pipes [14,29,30]. Gerhardt et al. found that 92 % of moonshine samples contained high, potentially toxic copper concentrations (i.e. 2100 – 14000 μg/L) [25]. The United States' maximum contaminant level for copper in drinking water is 1.3 mg/L [31] and in wine is 1 mg/L [32].

1.2. Methanol

Methanol is a common contaminant often found in home-distilled liquor samples worldwide [6,33,34]. Methanol is a natural byproduct of fermentation and is typically at low levels for most commercial alcohols. However, separating methanol from ethanol in home distillation necessitates precise temperature control, given that the boiling point of methanol is 66 °C, compared to ethanol's 78.37 °C. If this separation is not monitored closely, the home-distilled alcohol product may contain a dangerous level of methanol [5,35]. Levy et al. studied home-distilled alcohol in Romania and found methanol in 74 % of the samples tested, ranging from 0.06 to 8.6 gms/dL [36]. Methanol, a by-product of pectin metabolism in fruit, can vary in concentration depending on the pectin content of the fruit used in the creation of the mash at the beginning of the distillation process. Fermentation of fruits with high pectin levels typically results in increased methanol content [37–40]. Certain fruits such as grapes have a very low pectin content, 0.12–0.80 % by weight, therefore theoretically producing lower levels of methanol [41]. Other commonly used fruits and grains, such as corn or apples, have a much higher pectin content, approximately 2.44 % and 34.29 % by weight, respectively [42]. Croitoru et al. found that alcoholic beverages made with plum, apple, cornel, and oranges/bananas had higher concentrations of methanol (up to 2.39 % in plum alcohol) [39]. Paine and Dayan established that, in a drink containing 40 % alcohol per volume, the maximum tolerable concentration of methanol over two hours would be 2 % v/v [43]. The European Union sets conservative methanol limits (grams per hectoliter in 100 % vol. alcohol) with specific thresholds: 10 for vodka, 200 for wine spirit and brandy, 1000 for grape marc spirit and fruit spirit, and 1500 for fruit marc spirit [44]. While the US does not have a general methanol limit in distilled spirits, it does specify a maximum of 0.35 % v/v methanol in fruit brandy [45].

The human liver can naturally metabolize low levels of methanol, although its rate of elimination is slower compared to that of ethanol [46,47]. However, when an elevated amount of methanol (≥200 mg/L) is present in the body, the accumulation of its metabolic by-products such as formaldehyde and formic acid may potentially lead to scotomas, scintillations, and blindness [48]. Methanol concentrations exceeding 2000 mg/L have been associated with renal and liver damages, while acute toxicity developing around 5000 mg/L leads to reduced and involuntary movement, loss of consciousness, and even death [46]. A recent study reported that daily alcohol consumption of 100 g/day increases the relative risk of morbidity and mortality due to liver cirrhosis by factors of 8.15 and 16.38, respectively [49].

1.3. Glyphosate

Glyphosate (N-(phosphonomethyl) glycine) is a widely used broad-spectrum herbicide that works by blocking the shikimate pathway in plants [50]. It was introduced as a commercial herbicide (Roundup®) by the company Monsanto in 1974 as a non-selective herbicide [51] and is heavily used in agriculture to prevent the growth of weeds. Crops resistant to glyphosate have been engineered, enabling farmers to apply glyphosate as a herbicide without harming their cultivated plants. By 2009, over 80 % of the 120 million hectares of transgenic crops cultivated globally each year consists of strains resistant to glyphosate [52].

Unfortunately, the heavy use of this herbicide has caused various environmental and health effects [53,54]. Given the widespread use of glyphosate as an herbicide, its residue is likely to be present in consumer food and beverage products. Vineyards, plantations, and orchards, which are important in the production of alcoholic beverages, often undergo treatment with glyphosate-surfactant herbicides, leading to potential residues in fruits [55,56]. For example, glyphosate levels in German beer were reported to reach up to 30 μg/L [57]. Pérez-Mayán et al. detected glyphosate residues in 70 % of the red and white wine samples they analyzed with concentrations varying from 1.4 to 31.4 μg/L [58]. In a study focusing on the Latvian beer market, Jansons et al. found glyphosate level up to 150 μg/kg in beer samples [59]. Furthermore, a study of Swiss food products reported glyphosate in wine samples, with concentrations reaching up to 0.0132 mg/kg [60]. However, the presence of glyphosate in liquors has not been as extensively evaluated as in other consumer products.

Ingestion of glyphosate has caused several adverse health effects, including impaired renal function, metabolic acidosis, gastrointestinal damage, and death [17]. Glyphosate has been categorized by the World Health Organization's International Agency for Research on Cancer (IARC) as being "probably carcinogenic to humans" [61]. The US does not set a legal threshold for glyphosate in spirits, but the EPA does have regulations on the allowable limit in food groups [62]. For products commonly utilized in spirit production (grain, rice, and corn) the actionable limit ranges from 7 mg/L to 30 mg/L. The European Commission (EC)'s Regulation No 396/2005 established maximum residue levels (MRLs) for glyphosate in beer and wine at 0.1 mg/L [63]. To avoid potential health effects from long-term exposure, the glyphosate limit in US drinking water is set at 0.7 mg/L [31].

According to the World Health Organization, approximately 25 % of global alcohol consumption is in the form of unrecorded alcohol (e.g., moonshine, surrogate alcohols, etc.) [64]. In the United States, despite improved distillation equipment, home distillation processes still carry a risk of contamination in home distillation [65]. Therefore, this study focused on analyzing commercial and home-distilled alcohol samples from Texas, specifically testing for four common and hazardous contaminants - lead, copper, methanol, and glyphosate - which potentially pose serious public health risks.

2. Materials and methods

2.1. Reagents

J. T. Baker supplied the analytical-grade methanol and ethanol. Copper and lead standards (1000 mg/L in 2 % HNO_3) were purchased from High-purity Standard.

2.2. Sample acquisition

Commercial samples: Twelve commercially available alcohol samples of various brands were purchased from local markets in Killeen, Texas. All samples were given a unique ID for blind testing (C1–C12).

Home-distilled alcohol samples: Packets containing recruitment materials were distributed to businesses selling components often used in both home brewing and home distilling. Those agreeing to distribute packets were encouraged to give multiple packets to home brewers to then be distributed to other people who home distilled. Those who home distilled returned the packets to the research team using drop-off boxes. No questions were asked of any participants and no identifying information was collected. A total of 36 samples, all within the State of Texas from three large metropolitan areas, three suburban areas, and one rural area, were collected and submitted anonymously to Texas A&M University – Central Texas (TAMU-CT). Each of the home-distilled alcohol samples was given a unique ID for blind testing (M1-M36). All samples were stored in sealed vials at room temperature and prepared on the day of analysis. All materials and procedures were approved by the Institutional Review Board at TAMU-CT.

2.3. Preparation of standards and samples

Methanol: Twelve standard solutions with varying methanol concentrations of 10, 11, 12, 13, 14, 15, 20, 25, 30, 35, 40, 45 μL methanol/mL ethanol were prepared with 15 μL/mL of 2-propanol (2-PrOH) as the internal standard (ISD). Prior to measurements, both home-distilled and commercial alcohol samples were spiked with methanol and 2-propanol at final concentrations of 10 μL/mL and 15 μL/mL, respectively.

Lead: Five lead standard solutions with concentrations of 0.25, 0.5, 1.0, 2.0, 4.0 mg/L Pb were prepared from dilution of the 1000 mg/L Pb standard in ethanol. Prior to measurement, both home-distilled and commercial alcohol samples were spiked with Pb at final concentration of 0.25 mg/L.

Copper: Seven copper standard solutions at concentrations of 0.5, 1.0, 1.5, 2.0, 2.5, 3.0 and 3.5 mg/L Cu were prepared from dilution of the 1000 mg/L copper standard in ethanol. Prior to measurement, both home-distilled and commercial alcohol samples were spiked with Cu at final concentration of 0.5 mg/L.

Glyphosate: The preparation of five standards and 48 alcohol samples were carried out according to the method provided in the Abraxis® *Glyphosate ELISA, Microtiter Plate* kit.

2.4. Gas chromatography parameters

Gas chromatograph analysis was performed using a Shimadzu Gas chromatograph GC-2010 Plus equipped with a thermal conductivity detector. Helium, chosen as the carrier gas, maintained a constant flow rate of 1.5 mL/min. A Restek Rtx-1301 capillary column (with dimensions of 30 m length, 0.25 mm ID, and 0.50 μm film thickness) was used for methanol analysis with injection volume of 1 μL in splitless mode. The injector and detector temperatures were set to temperatures of 150 °C and 200 °C, respectively.

The oven temperature was initially kept at 35 °C and then gradually increased at a rate of 10 °C/min over a span of five minutes.

2.5. Atomic absorption spectroscopy parameters

Copper and lead levels were determined using a Shimadzu AA-6200 Atomic Absorption Spectrophotometer with acetylene as the fuel gas and compressed air as the oxidant. Copper and lead hollow cathode lamps were purchased from Hamamatsu Photonics K.K. with maximum absorption wavelength (analysis lines) of 324.75 nm and 217.00 nm, respectively. Each sample underwent three separate measurements, and the signal readings were then averaged.

Table 1
Concentration of target compounds in Texan home-distilled and commercial alcohols.

Group of alcoholic beverages	Sample number	Concentration[a]			
		Cu (mg/L)	**Pb (mg/L)**	Methanol (μL/mL)	**Glyphosate (μg/L)**
Texan home-distilled alcohol[c]	M1	2.82 ± 0.02	N/D	N/D	N/D
	M2	8.96 ± 0.15	N/D	12.47 ± 0.71	N/D
	M3	N/D[b]	N/D	11.10 ± 0.42	N/D
	M4	N/D	0.76 ± 0.13	9.49 ± 1.29	N/D
	M5	N/D	0.44 ± 0.20	11.47 ± 0.22	N/D
	M6	N/D	0.65 ± 0.14	2.38 ± 0.31	0.197 ± 0.011
	M7	N/D	N/D	1.28 ± 0.07	N/D
	M8	N/D	N/D	4.50 ± 0.51	N/D
	M9	N/D	N/D	N/D	N/D
	M10	N/D	0.47 ± 0.17	16.38 ± 0.97	N/D
	M11	N/D	N/D	14.78 ± 1.27	N/D
	M12	N/D	N/D	7.14 ± 0.10	N/D
	M13	N/D	N/D	13.11 ± 0.41	N/D
	M14	N/D	0.44 ± 0.17	11.17 ± 0.37	N/D
	M15	N/D	N/D	N/D	N/D
	M16	N/D	0.70 ± 0.13	12.89 ± 0.28	1.173 ± 0.108
	M17	N/D	N/D	14.71 ± 0.46	N/D
	M18	N/D	0.64 ± 0.15	7.15 ± 0.22	N/D
	M19	N/D	N/D	13.00 ± 0.74	N/D
	M20	N/D	N/D	3.86 ± 0.41	N/D
	M21	N/D	N/D	8.00 ± 0.84	N/D
	M22	N/D	N/D	4.97 ± 0.73	N/D
	M23	N/D	0.53 ± 0.16	6.55 ± 0.22	N/D
	M24	N/D	N/D	7.25 ± 0.74	N/D
	M25	N/D	N/D	N/D	N/D
	M26	N/D	0.49 ± 0.10	N/D	N/D
	M27	N/D	0.64 ± 0.10	18.80 ± 0.41	N/D
	M28	0.27 ± 0.01	N/D	22.29 ± 0.84	N/D
	M29	N/D	N/D	16.96 ± 0.93	N/D
	M30	0.55 ± 0.04	0.64 ± 0.16	8.88 ± 0.26	N/D
	M31	N/D	N/D	7.41 ± 0.07	N/D
	M32	N/D	N/D	5.52 ± 0.13	N/D
	M33	N/D	N/D	3.86 ± 0.16	N/D
	M34	0.55 ± 0.02	0.68 ± 0.07	22.68 ± 0.54	N/D
	M35	N/D	0.45 ± 0.10	7.29 ± 0.20	N/D
	M36	N/D	N/D	3.48 ± 0.20	N/D
Commercial alcohol[c]	C1	0.45 ± 0.01	N/D	11.39 ± 0.48	N/D
	C2	N/D	0.49 ± 0.10	3.46 ± 0.32	N/D
	C3	N/D	N/D	13.24 ± 0.13	N/D
	C4	N/D	N/D	12.77 ± 0.63	N/D
	C5	N/D	N/D	4.27 ± 0.42	N/D
	C6	N/D	N/D	2.16 ± 0.12	N/D
	C7	N/D	0.58 ± 0.21	10.32 ± 0.59	N/D
	C8	0.45 ± 0.04	N/D	7.95 ± 0.24	N/D
	C9	N/D	0.45 ± 0.13	11.12 ± 0.73	N/D
	C10	N/D	N/D	2.22 ± 0.13	N/D
	C11	N/D	0.45 ± 0.08	15.62 ± 0.20	N/D
	C12	N/D	N/D	8.38 ± 0.66	N/D

[a] The concentrations of the substances were presented as the mean values derived from three trials ($n = 3$), accompanied by their respective standard deviations (SD).
[b] N/D: Not detected, for the samples that gave signals below the limit of detection (LOD).
[c] No significant difference was found in the distribution of methanol and lead concentrations between commercial and home distilled liquor samples ($p > 0.43$ and $p > 0.16$, respectively). Statistical comparisons for copper and glyphosate were not feasible due to the limited number of samples with concentrations above the LOD ($n < 3$).

2.6. Limit of detection (LOD) and limit of quantitation (LOQ)

LOD and LOQ are determined using equations: LOD = 3 * S_{blank}/m and LOQ = 10 * S_{blank}/m, where m is the slope of the calibration curves for methanol, copper, and lead. The LOD and LOQ set for methanol were 0.06 μL/mL and 0.19 μL/mL; for copper were 0.03 mg/L and 0.09 mg/L; and for lead were 0.11 mg/L and 0.35 mg/L, respectively. Consequently, all the alcohol samples produced signals above the LOQ for methanol, copper, and lead were reported in Table 1. Any samples that gave signals below the LOD were labeled "Not detected". The Abraxis® *Glyphosate ELISA* kit reported a detection limit for glyphosate concentration at 0.075 μg/L.

2.7. Statistical analysis

The mean concentrations of methanol and lead in Texan home-distilled alcohols were compared to those of commercial alcohols using the unpaired *t*-Test. GraphPad Prism version 10.1.2 for Windows was used for statistical analysis with p-values less than 0.05 were deemed statistically significant (GraphPad Software, Boston, Massachusetts USA, www.graphpad.com).

3. Results

Table 1 showcased the concentrations of copper, lead, methanol, and glyphosate found in both commercial and home-distilled alcohol samples. The linear regression and 4 PL fit equations were reported in Table 2 with their respective correlation coefficients R^2 values ranged from 0.9983 to 0.9966.

3.1. Methanol

Detectable levels of methanol were present in 31 of the 36 home distilled samples, as well as in all 12 of the commercial samples (Table 1). All home-distilled and commercial samples possessed methanol concentrations below the informally permitted level of 0.35 % for brandy, as set by the US Food and Drug Administration [45]. No significant difference was found in the distribution of methanol content between commercial and home distilled liquor samples ($p > 0.43$).

3.2. Copper

There is currently no US legal standard for copper levels in distilled spirits. The U.S. Environmental Protection Agency has legal limit of 1.3 mg/L of copper in drinking water [31]. The FDA lowered the maximum allowable copper in wine from 1.0 mg/L to 0.5 mg/L [32]. Using the FDA standard for wine, four home distilled samples (11 % of group) exceeded 0.5 mg/L of copper, and no commercial samples exceeded this level (Table 1).

3.3. Lead

Currently, there are no regulations in the U.S. specifying a limit for lead concentration in alcoholic beverages. However, the EC has set a maximum lead content of 0.10 mg/kg in wine products produced from the 2022 fruit harvest onwards, as per Commission Regulation of the European Community No 2023/915 [22]. The EPA sets a maximum limit of 0.15 mg/L of lead in drinking water before taking action [21]. The lead content in 13 home distilled samples (36 % of group) and four commercial samples (33 % of group) exceeded the EPA and EC safety limits for lead in wine and drinking water (Table 1). No significant difference was found in the distribution of lead content between commercial and home distilled liquor samples ($p > 0.16$).

3.4. Glyphosate

Of the twelve commercial and 36 home-distilled alcohol samples analyzed, all but two home-distilled alcohols exhibited glyphosate

Table 2
Linear regression and 4 PL fit equations for Cu, Pb, MeOH, and glyphosate calibration curves.

Compounds	Equation	R^2	Sy.x	Sum of squares
Cu[a]	Y = 0.1050x + 0.02286	0.9991	0.003745	–
Pb[b]	Y = 0.02888x + 0.01538	0.9919	0.004592	–
MeOH[c]	Y = 1.100x - 0.1031	0.9962	0.05815	–
Glyphosate[d] (home-distilled)	$Y = 0.07364 + \frac{(0.8799 - 0.06371)x^{-1.288}}{x^{-1.288} + 0.3974^{-1.288}}$	0.9996	–	0.0001190
Glyphosate[d] (commercial)	$Y = 0.07364 + \frac{(0.8867 - 0.07364)x^{-1.494}}{x^{-1.494} + 0.4396^{-1.494}}$	0.9983	–	0.0006021

[a] The linearity range of Cu standard concentration was 0.50–3.50 mg/L.
[b] The linearity range of Pb standard concentration was 0.25–4.00 mg/L.
[c] The linearity range of MeOH/2-PrOH standard volume ratio was 0.667–3.000.
[d] The sigmoidal, 4 PL, range of glyphosate standard concentration was 0.075–4.000 μg/L.

levels below the detection limit of 0.075 μg/L (Table 1). The two exceptions had glyphosate concentrations of 0.197 μg/L and 1.173 μg/L (Table 1) which are considerably lower than the EC's established maximum residue levels (MRLs) of 0.1 mg/L for glyphosate in beer and wine [63].

4. Discussion

There exists a misconception that the consumption of unrecorded alcoholic drinks is mainly prevalent in socioeconomically disadvantaged countries. A recent report revealed that an estimated 20 % of the total alcohol consumed in the WHO European region is unrecorded [66]. Such beverages account for a significant proportion of alcohol consumption in various European countries, including Germany (10.4 %), Croatia (15.7 %), and Greece (41.3 %) [67]. While alcohol consumption is a well-researched leading risk factor for mortality and disability globally, the data can be skewed due to the presence of unrecorded alcoholic beverages with home-distilled alcohol being a prominent example [68]. Our group is the first to report the levels of substances of concern including copper, lead, methanol, and glyphosate in home-distilled alcohols from Texas and to address glyphosate concentrations in home-distilled alcohols broadly.

There is a long history of research of copper and lead impact on home-distilled alcohol [6–8,13,18–20,24,25,69]. There were four outliers in the home-distilled samples that exceeded the set standard for copper (0.5 mg/L) by the FDA for wine [32]. The largest outlier, sample M2 (8.96 mg/L, Table 1), was revealed by the person donating it to be over 50 years old, a family heirloom. This sample has been included in these results as it met all stated requirements for inclusion and indicates that home-distilling practices may have improved over the past 50 years. The outstanding elevated copper concentration can likely be traced back to the historical use of copper condensers and columns. This observation aligns with studies by Mosha et al. [6] and Nathan et al. [70] who reported copper concentrations of 0.1–31.2 mg/L in traditional African brews and 0.61–3.48 mg/L in water samples collected from refugee camps in India, respectively.

Research suggests that the primary source of toxicity in home-distilled liquors in the US is lead, which has become the focal point of many studies on home-distilled liquor [8,18–20,71]. Many home-distilled alcohols were produced by cost-effective methods employing materials like old car radiators or lead solders in the distillation process. Furthermore, lead also can infiltrate the environment, including water sources, due to the disposal of electronic waste containing lead solder [72]. Several studies, dating as far back as the 1980s, suggested links between severe lead poisoning and home-distilled alcohol consumption, with additional cases reported in subsequent years [7,19,20]. Prolonged consumption of poorly distilled alcohol can be detrimental, leading to serious health issues such as renal failure and neurological damage [73,74]. A recent study on unrecorded Albanian rakia highlighted that among heavy metals, copper and lead pose the greatest concern, leading to potential public health hazards [75]. Given that about one-third of the current samples was found to be above the current safety standards for lead, more research in this area is needed.

The current findings on methanol are in line with previous studies that suggested home-distilled alcohol in the US poses a relatively low risk to public safety in terms of methanol toxicity [8,13,25,33,34]. No reports of deaths from methanol poisoning due to moonshine consumption in the US were found since a 1953 study that recorded 41 fatalities [76]. Between 1993 and 1998, there were 2254 methanol poisoning cases reported annually in the US, with more than half resulting from the consumption of windshield wiper fluid [77]. Since the COVID-19 outbreak, the FDA has identified serious adverse health events, including fatalities, linked to the ingestion of alcohol-based hand sanitizers containing methanol [78]. A study in Korea found no trace of methanol 10 distilled liquors, although some refined rice and fruit wines contained methanol levels exceeding 1.42 mg/L methanol – still well below the safety threshold [79]. In contrast, elevated methanol levels were detected in 26 Romanian tuica (a home-distilled spirit) with nine samples surpassing the US legal limit of 0.35 % [36]. Such methanol presence in distilled alcohols often arises from subpar distillation procedures or inefficient equipment [80]. Methanol contamination levels in fermented alcoholic beverages from various countries are cause for concern, possibly due to the traditional use of mixed microbes during fermentation [40]. Havelec et al. proposed that methanol concentration may be used as an indicator for the authenticity of fruit spirits. Fruit spirits typically have higher methanol content compared to spirits made from grains or synthetic alcohol [81].

While numerous studies have explored glyphosate presence in beer and wine, our group is the first to investigate its concentrations in home-distilled samples. In our study, the highest level of glyphosate was 1.173 μg/L (Table 1), which is markedly on the lower end when compared to the range of 0.2 μg/L to 150 μg/L reported in beer samples from the Latvian market [59]. This is also beneath the lowest spiked level of 10 μg/kg tested in plant-based milk, wine, and beer [82]. The process of producing liquor involves fermentation of a fruit or grain, followed by distillation to concentrate the ethanol content. Given that the decomposition point for glyphosate, 189.5 °C, is remarkably higher than the 78.2 °C boiling temperature for ethanol during distillation [83], this could account for the low glyphosate concentrations in our samples. It was previously reported that the traceable amount of glyphosate and other agrochemicals found in beer and wort samples was significantly decreased following the wort boiling process during beer production [59]. Glyphosate, in low doses, is used as a chemical ripener to promote sucrose accumulation in sugarcane, a prime ingredient in the sugar-alcohol production process [84]. Therefore, fermented products like beer and wine are more likely to exhibit higher glyphosate concentrations than distilled products like commercial and home-distilled spirits.

4.1. Future research

There are global reports of methanol poisoning due to illicit alcohol use [3,5,85,86]. In Norway from 2002 to 2004, there were 59 reported cases of methanol poisoning, of which 17 resulted in death [4]. Furthermore, between 1963 and 2020, a total of 68 toxic methanol incidents were reported in the literature and media worldwide, leading to over 2243 fatalities [87]. Unfortunately, such incidences of methanol poisoning are often underreported, particularly with emerging online sale of unrecorded alcohols such as homemade, illicit, and surrogate varieties [88]. Recently, there has been growing apprehension regarding methanol and metal contamination in unrecorded fruit spirits (unregistered alcohols) across the European Union and Asia underscoring the need for a new alcohol regulation [66,67,89–91]. Specifically, the methanol, 1-propanol, 1-butanol, 2-butanol, iso-butanol, and isoamyl alcohol levels were found to be notably higher in unrecorded spirits compared to their recorded equivalents across Central and Eastern European countries [92]. Čonić et al. reported a potential health risk, regardless of drinking pattern, as elevated concentrations of methanol and acetaldehyde were confirmed in 17 % and 4 % of Serbian homemade spirits, respectively [93]. Concentrations of Cu [94,95], Zn [94], and Sn [94] were significantly higher in unrecorded spirits purchased informally from 31 individuals in 19 settlements in Eastern Hungary and from 127 private homes in Northern Serbia.

Our team is the first to document the levels of substances of health concern such as copper, lead, methanol, and glyphosate in home-distilled alcohols from Texas, as well as to examine glyphosate concentrations in home-distilled alcohols globally. Although this study provided valuable insights, its scope was limited to Texas. Future studies covering a broader region of the US and potential correlations between the type of beverage and the content of substances of concern would facilitate a more comprehensive evaluation of the potential health and clinical hazards associated with home distillation. Further analysis could be conducted to investigate the presence of other chemical toxins such as acetaldehyde, arsenic, and other polar pesticides thus identifying additional potential risks with consumption of home-distilled alcohols.

5. Conclusion

This study highlighted the necessity for updated alcohol regulations in the United States.

The data found that 33 % of commercial and 36 % of Texan home-distilled samples exceeded lead safety levels set by the EC for wine production. Four home-distilled alcohol samples surpassed the safety standards for copper in wine established by the Alcohol and Tobacco Tax and Trade Bureau. Levels of methanol and glyphosate were found to be within safe levels in all commercial and home-distilled samples. There is limited regulation of the substances examined in this study, therefore continuous chemical assessment of all consumed alcohol is a matter of public health.

Data availability

Sharing research data helps other researchers evaluate your findings, build on your work and to increase trust in your article. We encourage all our authors to make as much of their data publicly available as reasonably possible. Please note that your response to the following questions regarding the public data availability and the reasons for potentially not making data available will be available alongside your article upon publication.

Has data associated with your study been deposited into a publicly available repository?

Response: No.

Why: Data included in article/supp. material/referenced in article.

Declarations

All materials and procedures were approved by the Institutional Review Board at TAMU-CT (IRB # 2017010004).

CRediT authorship contribution statement

Coady Lapierre: Writing – review & editing, Writing – original draft, Methodology, Conceptualization. **Laura Weiser Erlandson:** Writing – review & editing, Writing – original draft, Formal analysis. **Randy Stoneroad II:** Writing – original draft, Formal analysis, Data curation. **Andrew Rhiner:** Writing – original draft, Formal analysis, Data curation. **Renae Gosnell:** Writing – original draft, Formal analysis, Data curation. **John Barber:** Writing – original draft, Formal analysis, Data curation. **Linh Pham:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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