ALCOHOLISM CLINICAL & EXPERIMENTAL RESEARCH

Composition of Unrecorded Distilled Alcohol (*bai jiu*) Produced in Small Rural Factories in Central China

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Background: Unrecorded traditional distilled spirits (*bai jiu*, 白酒) are made and used throughout rural China for everyday use and special occasions. Nearly every town or village has a distiller to supply the demand. In rural China, distilling *bai jiu* is legal and regulated lightly or not at all. The World Health Organization estimates that as much as 25% of all alcohol consumed in China is unrecorded alcohol, of which an unknown portion is unrecorded *bai jiu*. Little is known about the composition of unrecorded Chinese spirits from rural parts of the country. This study focused on white spirits because the high ethanol (EtOH) concentration makes them more likely to contribute to health risks compared to other types of lower alcohol by volume (ABV) Chinese unrecorded alcohol.

Methods: Researchers purchased samples of Chinese white spirits from small-factory distillers in central China. An independent laboratory conducted the analysis. Alcohol strength (ABV) was determined by hydrometer. Gas chromatography was used to determine the concentration of volatile organic compounds: EtOH, methanol, acetaldehyde, ethyl acetate, and higher alcohols. Samples were tested for 3 heavy metals—arsenic, cadmium, and lead. We used the guidelines developed by the Alcohol Measures for Public Health Research Alliance (AMPHORA) of the European Commission to assess risk.

Results: ABV ranged from 35.7 to 61.4%, and 58 of the 61 samples exceeded 40% ABV. The concentration of methanol, ethyl acetate, lead, arsenic, and cadmium was below AMPHORA guideline. The sum of higher alcohols exceeded the AMPHORA maximum in just 1 sample. Forty of the 61 samples had acetaldehyde levels beyond the AMPHORA guideline.

Conclusions: The unrecorded Chinese alcohols we analyzed had a high EtOH concentration—a public health concern that is also presented by recorded alcohols. The high percentage of samples (65.5%) that had elevated acetaldehyde suggests the need to investigate the causes for this result and the need for steps to reduce acetaldehyde levels. The cumulative long-term risks of using high EtOH and high acetaldehyde Chinese spirits are heightened by the percentage of people in China who have a genetic trait for impaired acetaldehyde metabolism.

Key Words: Acetaldehyde, *bai jiu*, Chinese White Spirits, Unrecorded Alcohol, 白酒.

UNRECORDED ALCOHOL IS an umbrella term that comprises alcoholic beverages produced or sold outside regular channels. Unrecorded alcohol can mean homemade alcohols (whether made illegally or legally), alcohol that is carried across national borders and, therefore, not recorded, any alcohol beverages produced, traded or sold in violation of local regulations, and alcohol that is not intended for human consumption but consumed by humans either directly or by mixing with other products (surrogate alcohol) (Rehm and Poznyak, 2015; WHO, 2014).

This paper describes the type of unrecorded Chinese distilled spirits known as *bai jiu* (白酒, literally "white spirits") that is legally produced outside a regulatory framework in small rural factories by people who follow traditional practices of *bai jiu* making. In China, spirits are the type of alcohol used by the majority of drinkers, and it is estimated that as much as 25% of the alcohol consumed is unrecorded (WHO, 2014). *Bai jiu* is the most common type of unrecorded alcohol, and it is produced in homes, in village artisanal distilleries, in temporary rural outdoor sites by itinerant alcohol makers, as well as in larger quantities by small-factory distillers (Qian et al., 2015). The total annual output of unrecorded *bai jiu* in China is unknown. However, there is such a large number of these small production sites throughout China that the total

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production each year is significant. The home-produced spirits are used by the family, and the surplus is traded or sold to a small network of customers. A larger annual quantity of unrecorded spirits is produced in small-factory distilleries, which distribute to a larger network of shops and eating/drinking places, thus enlarging the potential risk (Qian et al., 2015). The samples analyzed for this study were purchased from rural small-factory distilleries.

The alcohol industry is interested in reducing the amount of unrecorded alcohol produced in small unregulated facilities, as this production is in marketplace competition with the recorded alcohol, which typically is regulated and taxed (WHO, 2008). The industry has been joined by many in the public health community in suggesting concern about the safety of unrecorded alcohol, mainly pointing to the potential for adulteration or contamination in the unsupervised production and distribution system (Lachenmeier et al., 2009b, 2011). When adulteration or contamination does occur, there is typically a great deal of media attention that gives an impression of widespread risk. However, a global 2014 systematic review of chemical studies of unrecorded alcohol (Rehm et al., 2014) suggested that contamination is unusual and the danger to public health of unrecorded alcohol is comparable to that of recorded alcohol, in that both pose a risk to health resulting from the ethanol (EtOH) concentration. Rehm and colleagues (2014) added that it is the usually cheaper price that makes unrecorded alcohol riskier than recorded alcohol. There were no studies of Chinese unrecorded alcohol among the 29 chemical studies included in Rehm and colleagues' (2014) systematic review.

This paper describes the results of an analysis of 61 samples of unrecorded Chinese white spirits that were purchased from small factories in central China.

MATERIALS AND METHODS

Sampling

Researchers purchased 61 samples of 1 *jin* (500 ml) of locally produced distilled alcohols (*bai jiu*) from small factories in central China. The samples were ladled from large ceramic jars of the type traditionally used for storing *bai jiu* into the researcher's container. Samples were ladled into clean containers, sealed, and then refrigerated until delivered to the laboratory for analysis. The ceramic storage jars were labeled with price, strength, and sometimes the year of manufacture; however, the researcher did not record this information, so we could not compare label information with analysis results. *Bai jiu* prices tended to range from 4 to 14 RMB ($\approx$0.59 to 2.07 USD), with the stronger and longer-aged *bai jiu* costing the most. At each factory, researchers purchased 2 to 3 samples of different strength and age *bai jiu*. The merchants were not told about the purpose of these purchases.

Analysis of Samples

The amount of volatile organic compounds in each sample—EtOH, methanol, acetaldehyde, ethyl acetate, and higher alcohols—was measured using gas chromatography. Samples were tested for 3 heavy metals: arsenic (As), cadmium (Cd), and lead (Pb) using graphite furnace atomic absorption spectroscopy. Concentration of EtOH, which is reported in percentage alcohol by volume (ABV), was determined by hydrometer. See Appendix for details of the analyses used.

Analysis of Safety

The most widely accepted uniform international guideline for maximum safe levels of the compounds analyzed in unrecorded beverage alcohol samples comes from the Alcohol Measures for Public Health Research Alliance (AMPHORA) of the European Commission (Lachenmeier et al., 2011). AMPHORA has developed guidelines that suggest justifiable risk, which have become the de facto standard for estimating safety of unrecorded beverage alcohol. Findings from the analyses of these samples are compared to the AMPHORA guidelines. Lachenmeier and colleagues (2011) caution that a single sample exceeding the AMPHORA guidelines does not establish the existence of a public health problem. Use of the AMPHORA guidelines enables comparisons of analyses of unrecorded alcohols from different countries.

RESULTS

A tabulation of the results is shown in Table 1.

Ethanol

EtOH is a central nervous system depressant (National Institute on Drug Abuse, 2014), and with chronic use it is associated with more than 200 disease conditions (Rehm et al., 2010; Shield et al., 2013). The typical strength of commercially distilled alcohols is around 40% ABV. The EtOH in these samples ranged from 35.7% ABV to 61.4% ABV. Of the 61 samples, 58 (95.0%) exceeded 40% ABV: specifically, 3 (4.9%) of the samples had ABV <39.9%; 25 (41.0%) had ABV from 40.0% to 49.9%; 28 (45.9%) had ABV from 50.0 to 59.9%; and 5 (8.2%) had ABV >60.0%. Variation in EtOH content is the result of a number of factors in the manufacturing process: the yeast used for fermentation, the grain used, the temperatures during fermentation, the length of the time the grains ferment, and the length of the time for distillation. While a few *bai jiu* makers have a hydrometer, most of them rely on their training and experience to achieve the ABV of their product.

Methanol

Methanol is a natural by-product of fermentation, and it was present in 60 of the 61 samples tested. The concentration of methanol was below the AMPHORA guideline of 1,000 g/hl pa (Lachenmeier et al., 2011). Concentrations ranged from $\leq$0.05 to 197.9 g/hl pa. Methanol, commonly called wood alcohol, is a volatile compound often associated with surrogate alcohol and occasionally is a direct contaminant in unrecorded alcohol. Methanol is a central nervous system depressant (Fishbein, 1997). Formaldehyde, a product of methanol metabolism via alcohol dehydrogenase, is converted to formic acid via aldehyde dehydrogenase (ALDH). Formic acid damages the nervous system,

Table 1. Chemical Composition of Samples of Traditional *bai jiu* from Rural Central China

	g/hl of pure alcohol (pa)[a,b]					μg/l		
Sample	Ethanol (ABV%)	Methanol	Acetaldehyde	Ethyl acetate	Sum higher alcohol[c]	Arsenic[d]	Cadmium[d]	Lead[d]
1	55.2	16.2	44.5	316	51.4	2.4	n.d.	n.d.
2	49.4	7.0	12.9	28.7	10.6	0.5	n.d.	n.d.
3	52.8	50.5	183	353	155	n.d.	n.d.	n.d.
4	42.5	12.7	133	196	184	0.2	2.5	13.3
5	57.8	11.9	**53.9**	358	75.9	1	1	5.1
6	60.9	18.5	47.9	280	65.2	1.1	1.1	5.1
7	61.4	133	**223**	547	606	1.9	0.9	8.1
8	60.4	109	**154**	412	611	2.1	0.1	n.d.
9	59.8	28.5	**115**	351	166	2.2	0.2	1.5
10	60.1	18.4	14.0	56.4	5.1	2	0.5	4.7
11	48.0	16.7	27.4	217	11.2	n.d.	n.d.	n.d.
12	50.9	86.0	**395**	306	**1,102**	1	1.4	4.3
13	51.1	19.2	**80.0**	191	104	0.6	n.d.	6.7
14	52.3	17.2	28.4	23.6	56.0	0.1	n.d.	n.d.
15	49.2	14.0	**149**	336	102	1.2	n.d.	n.d.
16	52.0	8.5	24.0	183	42.6	n.d.	n.d.	n.d.
17	54.0	21.8	**164**	49.0	430	1.5	n.d.	5.1
18	56.3	22.4	**151**	130	463	0.1	n.d.	n.d.
19	54.6	25.9	**177**	84.3	393	0.2	n.d.	2.2
20	48.9	9.5	16.2	181	44.8	0.9	0.1	n.d.
21	45.3	16.9	36.6	93.0	33.5	1.1	0.5	0.6
22	38.8	0.0	**59.8**	289	18.1	0.1	0.3	5.5
23	50.9	7.2	47.7	63.2	37.8	0.4	3.6	4.9
24	47.6	40.2	23.5	139	27.6	0.4	n.d.	1.4
25	46.8	13.0	**59.8**	232	34.0	0.1	n.d.	40.5
26	51.1	17.8	**386**	210	377	0.2	1	0.6
27	51.1	6.6	**241**	292	327	0.2	n.d.	106.4
28	35.7	35.0	7.8	22.3	36.0	0.2	0.1	1.4
29	49.0	7.1	**117**	38.8	388	0.3	n.d.	n.d.
30	47.0	85.6	24.7	6.6	55.7	0.3	n.d.	n.d.
31	50.6	7.6	34.7	10.0	66.6	0.8	n.d.	1.5
32	49.0	8.9	**244**	40.6	424	n.d.	0.1	n.d.
33	45.6	198	**270**	82.9	437	1	0.6	4.2
34	48.0	106	17.5	138	34.6	0.9	0.1	0.2
35	52.2	48.3	**359**	677	406	1.2	0.5	14.3
36	47.2	38.6	**108**	94.8	104	3.3	n.d.	0.1
37	52.7	9.6	**154**	90.1	89.6	2.5	0.4	1.9
38	59.2	17.8	**55.0**	107	86.2	0.2	0.9	1.5
39	45.5	12.1	40.8	216	52.8	0.6	n.d.	4.6
40	53.6	54.3	**105**	276	76.6	0.3	n.d.	n.d.
41	50.3	13.8	38.9	95.7	14.4	3.3	2.2	10.4
42	55.0	40.5	**68.7**	245	64.3	0.8	0.1	n.d.
43	44.3	20.0	**56.1**	44.7	322	1.4	0.4	1.7
44	42.4	110	**91.4**	11.8	419	2.6	0.5	7.6
45	36.7	8.6	**125**	36.3	305	2.2	1.5	1.3
46	51.3	48.7	**119**	88.9	394	n.d.	n.d.	15.3
47	50.3	52.4	**124**	81.8	506	n.d.	n.d.	1.1
48	40.5	27.1	31.7	39.7	47.0	n.d.	n.d.	0.7
49	49.4	41.2	**59.2**	317	121	n.d.	0.1	7.5
50	50.4	34.9	**127**	19.9	129	n.d.	0.1	0.1
51	51.9	36.6	45.8	26.9	67.4	n.d.	0.1	n.d.
52	47.4	35.6	**113**	98.0	151	n.d.	n.d.	1
53	47.9	42.4	**63.6**	279	41.9	n.d.	n.d.	6.4
54	46.5	39.2	**103**	27.4	45.8	n.d.	n.d.	10.6
55	47.7	60.1	**206**	25.9	182	n.d.	n.d.	2.8
56	47.7	53.0	**225**	50.0	290	n.d.	n.d.	2.6
57	46.3	76.0	**86.4**	72.4	134	n.d.	1.1	2.4
58	50.3	50.9	**97.2**	20.9	138	n.d.	n.d.	n.d.
59	58.5	42.8	46.4	95.4	246	n.d.	n.d.	1.5
60	51.5	56.4	44.9	9.8	24.4	n.d.	n.d.	3.7
61	60.5	63.0	**72.7**	170	291	n.d.	0.1	n.d.

[a]Concentration of volatile compounds was obtained in mg/l and converted to g/hl pa by multiplying the obtained value by factor of 10/Alcoholic strength (ABV) for each sample.

[b]Detection limit for volatile compounds: 5 μg/ml.

[c]Sum higher alcohol is the sum of 6 different higher alcohols tested in the study: 1-propanol, 1-butanol, 2-butanol, isobutanol, isoamyl alcohol, and 1-hexanol.

[d]n.d. = not detected. The detection limit for nonvolatile elements was as follows: Arsenic, 0.21 μg/ml; Cadmium, 0.005 μg/ml; Lead, 0.01 μg/ml.

Numbers in boldface exceed the AMPHORA guidelines.

especially the optic nerve, and in the process of metabolism, also damages the liver and the kidneys (Bitar et al., 2004; Fishbein, 1997). We expected our samples to be low in methanol because *bai jiu* is made from grains, which have very low levels of pectin. The usual source of methanol in alcohol is from the high levels of pectin present when fruits are used in the production of some alcohols (Sakai et al., 1993).

Acetaldehyde

Acetaldehyde was present in all samples with concentrations ranging from 7.8 to 394.8 g/hl pa. Forty of the 61 samples (65.6%) had acetaldehyde concentrations above the 50 g/hl pa guideline set by AMPHORA. Acetaldehyde is carcinogenic and might be a contributor to alcohol dependence (Lachenmeier and Sohnius, 2008; Lachenmeier et al., 2009c; Zakhari, 2006). It forms early in fermentation when its concentration is the highest, and as fermentation proceeds, its concentration decreases, as some of it is reabsorbed by the yeast (Lachenmeier and Sohnius, 2008). So the length of time allowed for fermentation is important in determining the concentration of acetaldehyde. So too is what the maker does with the first distillate. Acetaldehyde has a low boiling point, so its concentration is highest in the first distillate.

Ethyl Acetate

Ethyl acetate is the most common ester found in beverage alcohols. All 61 samples contained a detectable amount of ethyl acetate. Concentrations ranged from 6.6 to 677 g/hl pa. At low levels, ethyl acetate is responsible for fragrance and the fruity odor of some alcohols, and at higher levels it lends a sharp vinegary taste sometimes related to spoilage (Apostolopoulou et al., 2005; Mingorance-Cazorla et al., 2003). All 61 samples were tested below the 1,000 g/hl pa guideline set by AMPHORA.

Higher Alcohols

Higher alcohols, or fusel alcohols, are natural by-products of alcohol fermentation by yeast and are important flavor compounds. The samples in this study were tested for the 6 higher alcohols most likely to be present in beverage alcohol. Other higher alcohols may have been present. The ranges for the 6 higher alcohols were as follows: 1-propanol, 4.3 to 808.7 g/hl pa; 1-butanol, not detected to 174.3 g/hl pa; 2-butanol, not detected to 187.6 g/hl pa; isobutanol, 0.2 to 121.2 g/hl pa; isoamyl alcohol, 0.1 to 265.8 g/hl pa; and 1-hexanol, not detected to 63.3 g/hl pa. AMPHORA has set the maximum limit of 1,000 g/hl pa for the sum of all higher alcohols. As the limit for individual higher alcohol is not available for the comparison, we calculated the sum of 6 higher alcohols in our 61 samples. The sum of the 6 higher alcohols listed ranged from 5.1 to 1,101.7 g/hl pa, with 1 of the 61 samples exceeding the limit. Higher alcohols have effects similar to EtOH, and potency might increase with chain length (Lachenmeier et al., 2008; Rehm et al., 2010). Few studies have linked the risk of unrecorded alcohol to the presence of higher alcohols (Lachenmeier et al., 2007; McKee et al., 2005). Table 2 provides results for each of the 6 higher alcohols.

Heavy Metals

Nonvolatile metals in unrecorded alcohol present a risk of carcinogenesis (Järup, 2003). Arsenic was detected in 41 (67.2%) of our 61 samples, with the concentration ranging from 0.1 to 3.3 μg/l. Cadmium was detected in 30 of our 61 samples (49.2%) with concentrations ranging from 0.1 to 3.6 μg/l. Lead was detected in 43 of our 61 samples (70.5%) with concentrations from 0.1 to 106.4 μg/l. Heavy metals enter unrecorded alcohol through the equipment used in distillation, the vessels used for storage, substances such as dilution water added during production, or from the soil in which the grains were grown (Ibanez et al., 2008).

Low doses of arsenic over time produce chronic effects to the skin, peripheral nerves, cardiovascular system, and central nervous system, and increase the likelihood of a range of cancers (Järup, 2003). The concentration of arsenic in all 61 samples was below the 100 μg/l guideline set by AMPHORA.

Cadmium is poisonous, and exposure is a factor for early atherosclerosis (Messner et al., 2009) and hypertension (Houston, 2007). The maximum limit for cadmium set by the AMPHORA for unrecorded alcohol is 10 μg/l. All 61 samples tested had concentration of cadmium below the AMPHORA guideline.

At certain levels, lead accumulates in soft tissue and the bones (Barry, 1975) and damages the central nervous system and causes blood disorders (Järup, 2003). The maximum limit for lead in unrecorded alcohol set by AMPHORA is 200 μg/l (Lachenmeier et al., 2011). Like the other 2 heavy metals, none of the 61 samples tested exceeded the AMPHORA guideline.

DISCUSSION

Chinese *bai jiu* is interwoven with tradition and lore, is a source of pride for those who make it, and is enjoyed for the same reasons by those who consume it (Qian et al., 2015). Unrecorded alcohol in Asia produced in homes and village artisanal distilleries appears to present little public health risk beyond the risks inherent in consuming EtOH (Lachenmeier et al., 2009a; Luu et al., 2014; Qian et al., 2015). Qian and colleagues (2015) reported that artisanal alcohol makers learned their craft from older, experienced makers, and followed well-established low-tech methods of manufacture. The home-based and village artisanal distillers typically made unrecorded *bai jiu* for personal and family use, and

Table 2. Details of Findings of 6 Higher Alcohols in the Samples of Chinese *bai jiu* From Central China

	g/hl pa						
Sample	1-Propanol	1-Butanol	2-Butanol	Isobutanol	Isoamyl alcohol	1-Hexanol	Sum
1	11.6	0.2	1.4	7.5	30.5	0.2	51.4
2	8.3	0.3	0.9	0.9	0.2	0.1	10.6
3	51.4	0.7	4.1	23.4	75.1	0.4	155
4	75.4	19.9	21.5	21.2	45.2	0.5	184
5	19.3	0.2	0.3	11.6	44.4	0.1	75.9
6	41.8	0.6	0.7	4.1	18.0	0.0	65.2
7	417	58.6	41.6	22.6	53.8	12.1	606
8	248	174	31.5	30.4	63.5	63.3	611
9	81.5	16.8	3.6	10.3	46.5	7.4	166
10	4.3	0.0	0.1	0.3	0.1	0.2	5.1
11	10.3	0.3	0.0	0.2	0.3	0.0	11.2
12	809	29.9	188	29.6	43.5	2.3	**1,102**
13	66.7	4.3	0.8	3.6	27.3	1.6	104
14	47.1	0.2	0.4	3.4	4.8	0.1	56.0
15	75.0	5.3	1.1	5.7	13.6	1.8	102
16	10.8	8.5	0.6	7.8	14.9	0.1	42.6
17	126	0.0	0.3	98.4	205	0.4	430
18	93.9	0.7	0.2	115	253	0.7	463
19	97.0	0.6	0.3	118	177	0.4	393
20	26.8	0.7	0.8	3.5	12.9	0.1	44.8
21	14.4	4.2	0.5	1.9	11.7	0.8	33.5
22	14.0	0.1	1.0	2.6	0.3	0.0	18.1
23	23.7	8.6	0.2	2.2	2.8	0.3	37.8
24	20.7	0.9	0.2	2.1	3.5	0.3	27.6
25	27.3	0.1	0.3	4.8	1.5	0.0	34.0
26	225	23.9	1.0	44.8	80.0	1.8	377
27	175	45.3	4.6	38.9	61.6	1.5	327
28	15.4	8.3	1.0	2.2	6.6	2.5	36.0
29	81.3	19.4	2.0	63.3	220	1.6	388
30	8.9	0.3	0.1	13.8	32.5	0.1	55.7
31	10.7	0.4	0.1	16.7	38.5	0.1	66.6
32	56.4	19.6	1.4	79.3	266	1.7	424
33	126	15.8	0.9	77.9	215	1.8	437
34	22.1	0.2	0.1	4.9	7.0	0.1	34.6
35	252	13.7	1.0	48.9	89.2	1.2	406
36	75.4	0.3	4.3	17.3	6.6	0.1	104
37	64.8	0.4	0.9	18.5	5.0	0.1	89.6
38	42.9	13.4	1.3	5.0	15.8	7.7	86.2
39	18.8	7.3	0.6	1.8	23.9	0.3	52.8
40	21.9	0.8	0.0	11.8	42.0	0.1	76.6
41	11.5	0.2	0.1	1.0	1.1	0.5	14.4
42	37.4	1.5	0.5	10.3	13.9	0.8	64.3
43	62.3	13.3	9.9	55.3	179	2.4	322
44	88.8	2.5	1.2	87.5	239	0.7	419
45	67.7	13.4	12.2	51.3	159	1.1	305
46	112	3.1	17.6	104	157	0.6	394
47	132	1.5	15.7	121	235	0.4	506
48	16.9	0.3	4.1	5.5	20.1	0.1	47.0
49	61.9	0.4	2.2	19.7	36.5	0.1	121
50	24.5	3.3	2.8	33.1	65.5	0.2	129
51	23.9	0.3	0.9	13.1	29.1	0.1	67.4
52	49.3	1.0	5.3	25.2	69.7	0.3	151
53	23.4	0.6	0.9	6.1	10.6	0.2	41.9
54	7.5	0.7	0.2	6.0	31.2	0.0	45.8
55	84.7	3.9	23.8	21.6	47.6	0.2	182
56	83.7	14.8	4.7	49.7	136	1.3	290
57	41.3	5.0	10.5	18.3	57.6	1.0	134
58	35.5	0.8	2.7	21.0	77.4	0.3	138
59	74.3	0.4	0.6	60.6	110	0.1	246
60	7.0	0.0	0.0	6.2	11.2	0.0	24.4
61	76.6	4.6	0.6	78.8	130	0.1	291

Values ≤0.05 are reported as 0.0. Numbers in boldface exceed the AMPHORA guidelines.

sold or traded to friends and neighbors in a limited geographic area. The social consequences to the maker of a defective product would be extreme.

In contrast, the samples analyzed in this study came from small factories that typically employed 3 to 6 workers. These facilities legally produce a larger annual quantity of alcohol, but still operate without much in the way of standards, regulation, or inspection. The motivation of the small-factory distiller is likely to be profit rather than tradition and lore, and he typically sells unrecorded spirits to a larger number of buyers, at least some of whom do not share a close social connection to the seller. Given these facts, there is less incentive in terms of pride, social consequences, or experience for the small-factory distiller to adhere to the highest level of safe production practices or product quality. Consequently, we expected we might find a wider range of results when analyzing the composition of their products, and we did.

Because little has been reported about the composition of unrecorded alcohols in China, we chose for comparison a separate analysis of 47 samples of unrecorded *bai jiu* purchased from home-based and village artisanal *bai jiu* makers in rural central China (Newman et al., 2016). The 47 samples were tested for the same components as the 61 samples reported here. For methanol, ethyl acetate, and higher alcohols, the 47 artisanal samples presented no remarkable findings. ABV levels in the artisanal *bai jiu* samples ranged from 38.7 to 63.7%. Three of the 47 samples of artisanal *bai jiu* had acetaldehyde above the AMPHORA limit. Three of the 47 samples of artisanal *bai jiu* contained heavy metals (Pb, Cd) above the AMPHORA limit. Both the 47-sample analysis and the 61-sample analysis suggest that concerns about public health consequences of unrecorded Chinese *bai jiu* should focus on ABV, heavy metals, and acetaldehyde.

EtOH Concentration (%ABV)

Analyses of unrecorded alcohols from other countries suggest that unrecorded alcohols typically have higher ABV than recorded alcohols (Rehm et al., 2010). We found no records of ABV from comparably priced recorded alcohol from this location in China with which to compare our results for unrecorded alcohol ABV. In the absence of other notable quality issues, it is the high EtOH concentration in unrecorded alcohol that presents the greatest health risk to consumers and to public health in general (Rehm et al., 2014). In general, this is the same health risk connected with the use of recorded or commercial spirits. However, unrecorded alcohol is usually cheaper than recorded alcohol, possibly increasing the public health risk attributed to unrecorded alcohol.

Of the 61 samples in this analysis, 58 (95.0%) exceeded 40% ABV. Forty percent ABV is a standard often used for distilled spirits in the United States and United Kingdom. The suggestion that unrecorded alcohols have higher ABV than recorded alcohol was based mainly on analysis of European samples (Rehm et al., 2010). Lachenmeier and colleagues (2013) analyzed a small sample of imported Chinese spirits purchased from shops in Germany and Canada and found the Chinese spirits ranged from 44.5 to 62.1% ABV (mean: 54.7%). The ABV in the 61 samples of small-factory-produced unrecorded *bai jiu* in this analysis ranged from 35.7 to 61.4% ABV (mean: 50.3%), that is, about the same as the EtOH content found in the imported Chinese spirits. In China's drinking culture, the ability of a male drinker to drink high-ABV spirits without showing any effects is viewed with admiration. One way to reduce the health risks from drinking is to reduce the alcoholic strength of spirits (Rehm et al., 2016; WHO, 2010). This would be difficult to achieve in the short term in China, especially among certain subgroups such as older men.

Heavy Metals

The presence of metals in unrecorded alcohol presents risks for carcinogenesis (Järup, 2003). None of the 61 samples of unrecorded Chinese *bai jiu* in this analysis contained arsenic, cadmium, or lead at levels above the AMPHORA limit. This is a small sample. Heavy metals in unrecorded alcohol do not usually present an acute toxic effect, but chronic exposure to low levels of heavy metals does present a public health risk. To the extent that the heavy metals are entering the *bai jiu* from the distillation equipment or the storage vessels, one can conceivably devise interventions to reduce heavy metals in unrecorded alcohol. If the source of the heavy metals is the local water supply or the local soils, then reducing exposure would be more difficult. A larger study with a larger number of samples needs to be performed to estimate the extent of heavy metals in unrecorded Chinese *bai jiu*.

Acetaldehyde

Newman and colleagues' (2016) analysis of 47 reference samples of home-based and village artisanal unrecorded *bai jiu* included only 3 in which acetaldehyde was detected above the AMPHORA guideline. Comparison the 61 samples of small-factory-produced unrecorded *bai jiu* in this analysis included 40 (65.5%) samples in which acetaldehyde was over the AMPHORA recommended limit. Lachenmeier and colleagues (2013) found high levels of acetaldehyde in 54.2% of the samples of imported Chinese spirits purchased from shops in Germany and Canada. Taken together, these analyses point to acetaldehyde levels in Chinese spirits as a potential public health problem.

Acetaldehyde levels in distilled grain spirits are affected by a number of factors: the yeast used, the fermentation process, exposure to oxygen during fermentation and/or storage, and microbial spoilage during production, possibly due to contamination in the processing facility (Kanteres et al., 2009). The knowledge and skill of the distiller also influences the acetaldehyde level in the final product, mainly through the distiller's decision when to separate the first distillate (which contains the most acetaldehyde) and how much to separate. There was no opportunity to observe the actual processes used to make the unrecorded *bai jiu* in the small factories from which the samples in this analysis were purchased, so we do not know for certain how the small-factory distillers handled the first distillate.

Acetaldehyde exposure contributes to cancer risk (Lachenmeier and Sohnius, 2008; Lachenmeier et al., 2013). Pflaum and colleagues (2016) noted the greatest cancer risk was for humans who have an inactive gene for producing the enzyme required to metabolize acetaldehyde. Among individuals who are heterozygous genotype ALDH2*1/*2, the incidence of malignant esophageal tumors is 12 times higher than for individuals who are homozygous ALDH2*1/*1. In the context of China, this is significant, as the proportion of the population with this genetic characteristic is estimated to be as high as 50% (Zakhari, 2006). Kanteres and colleagues (2009) suggest ideas for reducing acetaldehyde in unrecorded distilled spirits to the lowest levels technologically possible might be achieved through a culturally respectful education program for the small-scale distillers, or by paying a financial incentive to distillers who turn in their first distillate, or by forming artisanal alcohol cooperative ventures with quality control incentives for the individual member alcohol makers. It is possible one or all of these ideas could be tried in rural China, but the sheer number of small-scale *bai jiu* makers throughout China would make any of these ideas very difficult to implement in the short term. In addition to these supply-side strategies, Newman and colleagues (2015) suggested a demand-side strategy might be effective in reducing acetaldehyde exposure by means of brief educational messages for consumers, perhaps shared through social media to young people, that focus on people who exhibit facial flushing when drinking (a sign the person is ALDH deficient). The educational message would encourage drinkers who flush to reduce or stop drinking, and it would also encourage other people to refrain from pressuring a person who flushes to continue drinking. Like the supply-side strategies to reduce acetaldehyde exposure, this demand-side strategy would also be difficult to implement, in light of China's alcohol culture.

CONCLUSIONS

The analysis of 61 samples of unrecorded *bai jiu* from rural central China identified 2 health risks: the high EtOH concentration and the presence of high levels of acetaldehyde. Alcohol-related risks could be reduced with lower ABV products. The ABV in our samples was significantly higher than the standard 40% considered appropriate for spirits produced in the United States and England, but not significantly higher than reported for other distilled spirits available from China.

Our analysis did not support the suggestion that the ABV of unrecorded alcohol is higher than for recorded alcohol. However, the only reference analysis was Lachenmeier and colleagues (2013), which was a small sample of imported Chinese spirits purchased in shops in Germany and Canada. A direct comparison between recorded and unrecorded Chinese spirits made and sold in China is needed.

Our results support the suggestions that Chinese spirits (both recorded and unrecorded) may have higher than acceptable levels of acetaldehyde. This is a significant concern for China, which has a large proportion of the population who are ALDH deficient.

Our results do not identify the presence of heavy metals, but again this sample was small. Given the risk of long-term exposure, the presence of heavy metals in unrecorded spirits deserves further study.

Limitations

We can make no claim that the samples of unrecorded Chinese spirits we collected are representative of all of the unrecorded spirits in the region or in the country as a whole. We did not observe the distillation process for all of the alcohol samples we purchased, so we do not know how the distiller handled the first distillate. We have no way to judge the hygiene of the production facilities or the possibility of microbial spoilage for the samples we analyzed. When we purchased the samples from the small *bai jiu* factories in rural China, it was customary for the seller to ladle the *bai jiu* into our container from a quarter-ton to half-ton-size ceramic storage jar of the type that is traditionally used for storing *bai jiu*. We did not ask how many years the storage jars had been used for storing *bai jiu*. The ceramic storage jars typically were closed with a sandbag covered in heavy cloth (sometimes with a plastic sheet and heavy cloth), often held in place with elastic cords. We cannot say how completely the storage jars are sealed. We have no way to estimate the effect of this method of long-term storage on the level of acetaldehyde. There is clearly a need for more widespread testing of all unrecorded alcohols to determine their risk to public health.

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DECLARATION OF INTEREST

The authors have the following potential competing interests to declare:

Prior to 2014, Ian Newman was a member of the Research Advisory Committee of the International Center for Alcohol Policies (ICAP), Washington, DC. Prior to 2014, he received fees and travel support to attend meetings sponsored or cosponsored by the ICAP. Prior to 2013, Ian Newman consulted for the National Health Education Institute, Chinese CDC, Chinese Center for Health Education (CCHE)/Health News & Communication Center, Ministry of Health (HNCC, MOH). In the past 5 years, he has received University of Nebraska employment-related funding from the U.S. Department of Education, the Nebraska Department of Health and Human Services, the Nebraska Department of Roads/ Nebraska Office of Highway Safety. As American deputy director of the American Exchange Center at Xi'an Jiaotong University, Newman received funds from the U.S. State Department and the University of Nebraska. Ian Newman owns an equity interest in The Buffalo Beach Company (Lincoln, Nebraska) and has received consulting fees from The Buffalo Beach Company for independent research on indigenous alcohol use and traffic safety.

Ling Qian was a member of an ICAP advisory committee and has received fees and travel support to attend and to speak at meetings sponsored or cosponsored by ICAP. Through The Buffalo Beach Company grant from ICAP, Qian Ling has received fees for assisting in the organization of and data collection for projects funded by ICAP. Her regular salary was paid by the Chinese government through the Chinese Center for Health Education.

Niran Tamrakar, Yonghua Feng, and Ganrong Xu have no competing interest to report.

APPENDIX. Details of Materials and Methods Used to Analyze Samples of Chinese Bai Jiu

DETERMINATION OF VOLATILE ORGANIC COMPOUNDS

Gas chromatography was used to determine the concentration of volatile organic compounds: EtOH, methanol, acetaldehyde, ethyl acetate, and higher alcohols. The results for each sample were recorded as mg/l and converted to g/hl of pure alcohol (pa) by multiplying the recorded value by the factor of 10/EtOH concentration (ABV). Grams per hectoliter of pure alcohol (g/hl pa) is the measure recommended by the European Commission (2000). The apparatus consisted of Shimadzu GC-2010, PE Turbo matrix 16 (head space sampler), Flame ionization detector, and OV1701 column. The operating conditions were as follows: injector temperature, 160°C; detector temperature, 260°C; column temperature, 40°C (3 minutes) to 180°C (2 minutes)/10°C; carrier gas, N_2, 23 kPa; flow rate, 5 ml/min; air flow rate, 400 ml/min; H_2 flow rate, 47 ml/min; makeup gas, 30 ml/min; head space conditions, vial temperature: 70°C; thermosetting time, 25 minutes; pressurization time, 25 minutes; transfer line temperature, 130°C.

DETERMINATION OF HEAVY METALS

Samples were tested for 3 heavy metals: As, Cd, and Pb using graphite furnace atomic absorption spectroscopy. A SpectrAA 220/220Z graphite furnace atomic absorption spectroscopy (Varian) consisting of element hollow cathode lamp (Vigorous) was used to determine the concentration of these metals, which are reported in units of μg/l. Reagents used in the analytical process were nitric acid, hydrochloric acid, high chlorine acid (guarantee reagent), and ultrapure experimental water. For standard reserve liquid, the concentrations of As, Cd, and Pb were 1,000 μg/l for each element and were purchased from a national chemical reagent quality inspection center. For standard application liquid, the concentrations of As and Pb were 20 ng/ml and 2 ng/ml for Cd. The reserve liquid was diluted with 5% HCl (v/v) to different concentration. The instrument was adjusted to different wavelengths and atomization temperatures to determine a particular metal concentration as illustrated in Appendix Table A1.

For the purpose of quantitative analysis of heavy metals, liquor samples were first digested. For this, 200 ml of liquor sample was placed in the beaker, which was heated to remove alcohol and water from the sample. The heating was stopped when the volume of sample reached 2 ml. Transfer of the residual liquor to the flask was followed by the addition of 2 ml nitric acid (HNO_3) and 0.5 ml of perchloric acid ($HClO_4$). The mixture was heated until the clear liquid was obtained or the volume of the mixture was 0.5 ml. The ultrapure water was added to the digested sample to reach the 25 ml mark in the flask. Then 1 to 2 ml of the digested sample was acidified using 5% HCl and placed in the reactor of the instrument to calculate the concentration of heavy metals.

Table A1. Working Conditions for GFAAS

Element	Wavelength spectrum (nm)	Width (nm)	Lamp current (mA)	Atomization temperature (°C)
As	193.7	0.5	6	2,300
Pb	283.3	0.5	2	2,100
Cd	228.8	0.5	3	1,800

GFAAS, graphite furnace atomic absorption spectroscopy.

DETERMINATION OF ALCOHOL BY VOLUME (ABV%)

Concentration of EtOH was reported in percentage alcohol by volume (ABV%). Alcohol strength was determined by hydrometer. A 100 ml liquor sample was transferred into a 500 ml distillation flask with 100 ml of distilled deionized (DD) water. The solution was distilled by electric stove, and the distillate was collected into 100 ml volumetric flask, which was in ice water. Distillation was stopped when the distillate approached the 100 ml mark. The hydrometer was placed in the collected distillate and allowed to float. The mark at which the liquor level crossed the stem of the instrument was recorded, and the concentration of alcohol or EtOH in each sample was calculated according to temperature.

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