Fraud and Misrepresentation in the Lump Charcoal Market in the United States: A Closer Look Inside the Bag

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Abstract

In the United States, charcoal is widely used for recreational purposes, particularly as fuel for outdoor grilling. Unknown to many consumers, charcoal production has profound environmental impacts worldwide and is too often linked to deforestation and illegal activities involving fraud and misrepresentation in the forest products supply chain. At present, the reliability of the US charcoal market is largely unknown. For 15 lump charcoal brands in the US commercial market, we evaluated the taxonomic composition, claims of origin, bag weight, and lump size. All 15 brands analyzed exhibited substantial inconsistencies compared to the information provided on the packaging. These discrepancies included taxonomic misidentifications, misrepresented claims of origin, and discrepancies with bag weight. This study is broadly consistent with previous findings of fraud and misrepresentation in the forest products supply chain in the United States and in the charcoal trade in Europe and suggests that lump charcoal consumers are frequently using material that differs substantially from product claims.

Forest biomass holds tremendous promise as a renewable resource capable of addressing critical global challenges for building materials, energy, and other uses. It offers sustainable solutions for fuel and heating, enhancing energy security, and mitigating resource depletion (Easterly and Burnham 1996, Hall 2002, Ang et al. 2022, Bays et al. 2024, IEA Bioenergy 2024). One prominent example is wood fuel, which has served as a vital source of energy for cooking and heating worldwide for centuries if not millennia. This practice continues today, with an estimated 2.4 billion people relying on wood fuel annually (Serrano-Medrano et al. 2014, van Dam 2017). While the exact split between fuelwood and charcoal use remains unclear, it is likely that hundreds of millions of people globally depend on charcoal (Wilkinson et al. 2007, van Dam 2017, van't Veen et al 2021).

However, the use of wood for fuel extends beyond basic subsistence needs. In contrast to fuelwood used for daily life in developing countries throughout the world, recreational use of charcoal is common in many places, such as Europe and the United States (Reumerman and Frederiks 2002, Mencarelli et al. 2025). Celebrated for its natural flavor and ability to impart a distinct smokiness to grilled foods, lump charcoal plays a central role in outdoor cooking traditions across the United States. However, the production process behind this popular cooking item and its potential consequences are often unknown to consumers.

Charcoal production can be associated with environmental and ethical concerns. It is frequently linked to deforestation,

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unsustainable practices, illegal logging, and illicit trade (Interpol 2015, van Dam 2017, Nellemann et al. 2018, Haag et al. 2020, Perdigão et al. 2020, Zahnen et al. 2020, Braga Junior et al. 2021, da Silva et al. 2024). These issues are not confined to the producing countries; they directly impact the charcoal supply chain that feeds U.S. grills. To understand these complexities, it is crucial to examine the charcoal sold in the United States.

The United States imports substantial charcoal volumes (including lump charcoal and briquettes), primarily from neotropical countries such as Mexico, Paraguay, and Brazil (USITC DataWeb 2024), regions where charcoal production is linked to environmental and social challenges, including deforestation (Taylor 2008, da Ponte et al. 2017, Prayogi et al. 2020, García-Quezada et al. 2022, Fenton 2024), forest degradation (Gonçalves et al. 2016), potential links to illegal logging (Perdigão et al. 2020, da Silva et al. 2024), and resource theft (Haag et al. 2020, Braga Júnior et al. 2021).

Analysis of charcoal import data for the United States from 2019 to 2024 reveals distinct patterns among exporting countries, with Mexico being the main supplier. In 2019, the country accounted for 69.83% of US charcoal imports, reaching 71.57% in 2020 before declining to 61.23% in 2024. Despite this decrease, Mexico maintained its dominant position by a substantial margin. Paraguay demonstrated an increase in its contribution, emerging as the second-largest exporter. Starting with a 3.79% share in 2019, Paraguay's contribution almost doubled, reaching 7.11% in 2020 and peaking at 12.64% in 2021. By 2024, Paraguay supplied 10.64% of US charcoal imports, establishing itself in the second position. Indonesia and Brazil consistently ranked among the top five exporters during this timeframe. Indonesia's share fluctuated, starting at 3.87% (2019), reaching a high of 6.56% (2022), and registering 5.44% in 2024. Brazil also maintained its share, ranging from 3.28% (2019) to a peak of 4.63% (2020), and recorded at 4.01% in 2024. Other notable contributors to the US charcoal supply include South Africa, Venezuela, Colombia, El Salvador, and Nicaragua (USITC DataWeb 2024). This reliance on imports, particularly from neotropical countries, raises concerns about the sustainability and ethical sourcing of charcoal sold in the United States (Magrath et al. 2010).

As a major supplier of charcoal to the United States, Mexico's charcoal production presents a complex picture. While it provides crucial livelihoods in rural areas, it also contributes to deforestation and forest degradation (Taylor 2008, García-Quezada et al. 2022), the labor-intensive nature of charcoal production often results in harsh working conditions and low wages, and the trade itself can be linked to illegal activities such as wood theft and the clearing of protected areas (Taylor 2008).

Similarly, deforestation in Paraguay is a complex issue driven by a combination of factors, including agricultural expansion, charcoal production, and corruption (Haag et al. 2020). While the Zero Deforestation Law has had some success in reducing deforestation in Paraguay's Atlantic Forest (da Ponte et al. 2017, Fenton 2024), challenges persist in the Gran Chaco Forest which is still facing pressure due to the demand for charcoal (Prayogi et al. 2020).

Brazil, another key charcoal exporter, faces its own set of challenges. Charcoal production in Brazil is often associated with environmental crimes such as land grabbing and deforestation, as well as labor exploitation (Braga Júnior et al 2021). A particularly pressing issue is the use of illegal wood from protected indigenous lands in the Amazon for charcoal production (Perdigão et al. 2020). This illegal practice is exacerbated by a lack of resources for monitoring the origin of the wood, leaving protected areas vulnerable to illegal logging (da Silva et al 2024). Additionally, charcoal production in the threatened cerrado biome contributes to deforestation and environmental degradation (Gonçalves et al. 2016).

In addition to importing lump charcoal, the United States itself produces lump charcoal for use within the country. Specifically, several lump charcoal brands pose a range of claims asserting production from US woods.

For some time, there has been increasing awareness about the environmental (Taylor 2008, Pandey et al. 2009, Kabir et al. 2010, Chidumayo and Gumbo 2013, van Dam 2017, Mencarelli et al. 2023) and social impacts (Dias et al. 2002, Nellemann et al. 2018, Dittmar 2024) of charcoal production, prompting consumers to seek sustainably sourced and ethically produced charcoal (Rocchi et al. 2023). However, the complexity of the charcoal supply chain, coupled with a lack of transparency and regulation, makes it challenging for consumers to make informed choices (van Dam 2017).

In 2015, the European Union (EU) began to tackle the environmental crime wave by studying the charcoal trade. They found that it was a major source of income for organized crime and terrorist groups (Interpol 2015). In 2020, the Thünen Institute and the WWF conducted an analysis of the charcoal trade in Europe. They studied 30 fragments from each of 150 charcoal consignments from 11 countries (a total of 4,500 individual charcoal fragments, both from lump charcoal and briquettes) and found that 46% of the charcoal in Europe was from subtropical or tropical regions; only 25% of the consignments examined provided information on the bags regarding the processed woody taxa; and over half of the information provided was incorrect or incomplete (Haag et al. 2020, Zahnen et al. 2020). The conclusion of these studies causing major concern is that the charcoal trade in Europe is a major source of income for organized crime, is associated with illegal logging and deforestation, and lacks regulation and control (Interpol 2015, Nellemann et al. 2018, Haag et al. 2020, Zahnen et al. 2020).

In 2019, Wiedenhoeft et al. revealed a concerning incidence of fraud and misrepresentation in wood-based products within the US market, with nearly two-thirds of products showing some form of fraud and/or misrepresentation. However, their investigation did not extend to charcoal products, leaving a critical gap in our understanding of the integrity of this market segment in the United States. Consequently, the prevalence of fraud within the US charcoal market remains unclear.

To address this gap this study aims to provide an analysis of a snapshot in time of the lump charcoal trade in the United States by investigating the taxonomic composition, origin, weight, and inclusion of noncombustible materials based on the transparency of product labeling. Furthermore, we assess lump size classes to determine if a given bag of lump charcoal shows different taxonomic composition by size class. By addressing these objectives, this research seeks to evaluate the reliability of claims for lump charcoal, inform charcoal consumers, guide manufacturers, and offer regulators valuable insights into the potential need for industry guidelines, oversight, and enforcement.

Material and Methods

Charcoal acquisition

Fifteen lump charcoal brands were selected for this study, representing the major companies operating in the North American charcoal market. Bags were purchased online between February and November 2019. As noted in more detail below, individual manufacturers are not named in this work, but manufacturer names were provided to the editors for review.

Packaging claims

All information displayed on product packaging was considered a "product claim" and used for analysis. Each bag was assigned a unique specimen code (1 through 15), and data including brand, manufacturer, declared country of origin, declared product weight, and declared woody taxa were recorded in a spreadsheet. Brand and manufacturer information are not disclosed in this manuscript. This decision aligns with the approach taken by Wiedenhoeft et al. (2019), where the intention is not to "name and shame" but rather to contribute scholarly data to the broader understanding of fraud and misrepresentation in the US lump charcoal market.

Charcoal weight

To assess compliance with labeling regulations, the total weight of the contents of each bag was measured in grams and compared to its labeled net weight (converted from pounds to grams). Acceptable weight variations were determined according to the Fair Packaging and Labeling Act (FPLA) Section 500.25(c) and the National Institute of Standards and Technology (NIST) Handbook 133. These guidelines define "Maximum Allowable Variations" (MAV) that are considered reasonable variations permitted for individual bags. Table 1, adapted from Table 2-5 in NIST Handbook 133, presents the Maximum Allowable Variations (MAVs) for the specific weights of the charcoal bags analyzed in this study.

The difference between the claimed weight and the actual measured weight was calculated to determine weight discrepancy. A normalized discrepancy metric (d) was calculated to express the discrepancy relative to the MAV:

$$d = |\text{claimed weight} - \text{actual weight}|/\text{MAV}$$

Weight discrepancies were categorized based on how much they exceeded the MAV. Eight ranks of discrepancy were created and detailed in the "Weight Claim" column in Table 2.

To assess the accuracy of product claims across various categories (taxa, origin, and weight), we developed an ordinal discretization method detailed in Table 2.

Table 1.—Maximum allowable variations (MAVs) for bags labeled by weight (adapted from Table 2–5 in NIST Handbook 133).

Maximum Allowable Variations (MAVs) for Bags Labeled by Weight	
Labeled quantity	Maximum allowable variations
More than 3.58 kg to 4.26 kg	86 g
More than 7.90 lb to 9.40 lb	0.19 lb
More than 4.26 kg to 5.30 kg	99 g
More than 9.40 lb to 11.70 lb	0.22 lb
More than 6.48 kg to 8.02 kg	127 g
More than 14.30 lb to 17.70 lb	0.28 lb
More than 8.02 kg to 10.52 kg	140 g
More than 17.70 lb to 23.20 lb	0.31 lb

Lump size analysis

We aimed to determine the relationship between charcoal lump size, taxonomic composition within each size class, and the weight distribution by size class. To achieve this, we utilized a human-powered sifting machine, specifically designed for this purpose, equipped with three progressively smaller mesh screens (2-inch, 1-inch, and half-inch) to separate the charcoal pieces by size. This process yielded four distinct size classes: those specimens that did not pass through a 2-inch mesh, those that did not pass through a 1-inch mesh, those that did not pass a through a half-inch mesh, and "fines" (particles that passed through the half-inch mesh and collected in a base tray). The weight of charcoal retained in each size class was recorded.

It is important to acknowledge that the brittle nature of charcoal makes it susceptible to fragmentation during handling, packaging, and transportation. This inherent fragility may influence the observed size distribution relative to the size distributions originally bagged by the manufacturer. Later in the "Lump size screening" results section we consider it possible that our sifting method could have increased the fines portion of the charcoal over what a consumer might find in the bag from the manufacturer. Furthermore, our sifting method doubtless caused some fragmentation of larger size-class pieces, shifting the distribution an unknown amount toward smaller size classes. Based on observations of material before and during sifting, the frequency of this at the larger size classes was comparatively infrequent.

While we recognize the established link between lump size and combustion characteristics (CEN EN 1860-2:2005 n.d.), our analysis of size distribution was not intended to assess combustion quality explicitly. Instead, our focus was to determine whether smaller size classes showed similar taxonomic membership and breadth to the larger size classes, or if different taxa were utilized at smaller size classes, perhaps to achieve the stated net weight of the bag, though if a bag of charcoal showed a proportion of fines by weight greater than Fines/(MAV*2), we considered that an undesirable condition.

Taxonomic identification

Due to the brittle nature of charcoal, traditional sectioning for microscopic analysis is not available (Angeles 2001). Charcoal fragments were oriented for examination using a 14x hand lens and/or reflected light microscopy, as needed. Identification of challenging taxa was facilitated by use of the online tool InsideWood (Wheeler 2011). Final taxonomic identification was achieved by comparing charcoal anatomical features to reference specimens in the xylarium and slide collection at the Forest Products Laboratory in Madison, Wisconsin. All charcoal fragments within each bag were analyzed, totaling over 18,000 individual pieces examined both macroscopically and/or microscopically for taxa requiring light microscopy for identification.

Table 2.—Evaluation criteria for charcoal product claims.

Rank	Taxonomic claim	Origin claim	Weight claim
1	Only and all listed taxa	Entirely consistent with origin claim	d < MAV
2	Only listed taxa, but not all listed taxa		1MAV < d < 2MAV
3	Listed taxa and unlisted taxa from a similar forest type	Partly consistent with origin claim	2MAV < d < 3MAV
4	No listed taxa, but taxa from similar forest type		3MAV < d < 4MAV
5	Listed taxa and unlisted taxa from a dissimilar forest type	Inconsistent with origin claim	4MAV < d < 5MAV
6	No listed taxa, but taxa from a dissimilar forest type		5MAV < d < 6MAV
7	Broad, vague claim (e.g., hardwood, or wood)	Broad, vague claim	6MAV < d < 10MAV
8	No claim	No claim	d > 10MAV

For weight claim, d is the discrepancy metric, compared to the MAV.

Results and Discussion

Analysis of 15 commercial charcoal brands revealed inconsistencies between packaging information and actual product composition in 12 (80%) products. These discrepancies included vague labeling, equivocal taxonomic composition, and inaccurate weight. Furthermore, when the amount of material unusable or unreliable for grilling (bark [which combusts quickly and unevenly], rock, and fines) was considered, the number of products exhibiting inconsistencies increased to 15 (100%), each of which are detailed below.

General packaging information

Analysis of packaging revealed a lack of transparency regarding woody taxa and origin. Eight (53%) bags specified the woody taxa used by common name (Table 3), with the remaining seven (47%) stating only that the charcoal was derived from "hardwoods," a claim so broad that it imparts little context.

Of those that claimed explicit taxa,

- one bag claimed, "100% mesquite."
- one bag declared, "One ingredient: oak hardwood."
- one bag listed "oak, hickory, maple, and other hardwoods."
- one bag claimed, "All natural Lump Oak and Hickory." It is not clear if the claim is all-natural, or if the bag's contents are all lump oak and hickory.
- four bags listed one-to-three taxa but did not specify if these were the only woods used. These four bags used the term "100%" in association with "natural" and/or "hardwoods," sometimes followed by a list of taxa.

Seven bags did not declare particular taxa but stated that the charcoal was derived from hardwoods, using variations of phrases like "100% Natural Hardwood" or "All Natural Hardwood Lump Charcoal" (Table 3). Claims like "100% Natural" and "Environmentally friendly" are presumably used to appeal to those consumers seeking sustainable and natural products. However, these claims can be misleading, vague, and may exaggerate environmental impacts (de Freitas Netto et al. 2020). Phrases like "Renewable Natural Resources" might suggest responsible sourcing, but only one of the bags displayed a third-party certification seal. The term "100% Organic Hardwood" can also be deceptive. In the United States, the USDA strictly regulates the use of the term "organic" (AMS 2000). Authentic "organic" products must display the USDA Organic certification seal, a rare occurrence in the charcoal industry due to the stringent certification process. The bag in question did not display the USDA certification seal. Of the 15 bags, only one (#14) claimed Forest Stewardship Council (FSC) certification, but we were unable to verify the specific FSC certificate applicable to this bag (Table 3).

The examination of charcoal packaging also revealed inconsistencies in how countries of origin were presented (Table 3). Of the 14 bags that included origin information, most (9) used the phrase "Made in," while five used "Product of", with one simply stating "America," which is too broad to be informative. The countries identified on the bags were Brazil (1), Canada (1), Mexico (5), Paraguay (1), Ukraine (1), and the United States (4). This small sample aligns roughly with the US charcoal import trends from 2019, the year of sample collection. According to USITC DataWeb data for 2019, Mexico already dominated the market then, supplying approximately 69.83% of US charcoal imports by quantity. Indonesia and Paraguay followed with 3.87% and 3.79%, respectively. While our sample included charcoal from Brazil and Canada, their contributions to the US market were relatively small in 2019 (3.28% and 0.87%, respectively) (USITC DataWeb 2024). Due to the limited sample size, our analysis may not fully represent the entire market panorama of that year. For example, in 2019 Indonesia accounted for approximately 3.87% of US charcoal imports (USITC DataWeb 2024) but was not represented in our findings. Conversely, Ukraine, which in 2019 contributed less than 0.05% of US charcoal imports, was a claimed origin in our 2019 sample. In addition to limits of sample size, the USITC data include both lump and briquette charcoal, but this study was restricted to lump charcoal, and this could contribute to discrepancies between trade data and our findings.

Haag et al. (2020) reported concerning discrepancies with charcoal packaging labels in the European Union (EU). They found that only a quarter of the examined charcoal bags displayed information about the woody taxa used, and over half of those labels were inaccurate or incomplete. This prior work, in conjunction with our results, highlights that labeling issues are not unique to the US charcoal market, suggesting the potential for a broader problem.

We approach the analysis of our results in two broad areas: a combination of taxonomic composition and claimed origin (as one bears on another for inferring consistency with product claim), and bag weight. Within these areas and based on our observations, we also group claims and results in an endeavor to summarize interesting patterns.

Table 3.—Claimed vs. observed charcoal taxonomic composition, claimed origin and number of fragments analyzed in each size class.

#	Claimed taxa	Observed taxonomic composition	Claimed origin	N each size class	
1	Oak, Hickory, Maple	*Quercus* (Oak) (71.11%), *Carya* (Hickory) (7.21%), *Acer* (Maple) (0.21%) + *Alnus* (0.12%), *Tilia* (0.12%), *Fraxinus* (0.10%), *Platanus* (0.05%), *Ulmus* (0.04%), and *Juglans* (0.03%)	Made in USA	2" 1" ½"	44 648 2197
2	Oak	*Quercus* (Oak) (74.61%) + Anacardiaceae (0.92%), *Neltuma* (0.10%)	Made in Mexico	2" 1" ½"	62 319 308
3	100% Hardwood	Fabaceae (96.95%)	Product of Brazil	2" 1" ½"	90 245 873
4	Hardwood	*Aspidosperma* (98.73%)	Made in Paraguay	2" 1" ½"	42 301 216
5	100% Natural Hardwood	*Neltuma* (31.55%), Fabaceae (14.84%), *Albizia* (8.97%), Sapotaceae (7.89%), *Eucalyptus* (7.06%), *Ulmus* (6.69%), *Cordia* (5.59%), Euphorbiaceae (3.90%), Unknown (2.38%), *Rhamnus* (1.77%), *Ceanothus* (1.52%), *Ficus* (1.40%), *Quercus* (0.70%), *Pistacia* (0.58%), *Xerospermum* (0.55%), Anacardiaceae (0.38%), *Fraxinus* (0.19%), *Castanea* (0.06%), Sapindaceae (0.02%)	Product of Mexico	2" 1" ½"	38 211 1140
6	100% Natural Hardwood	*Fraxinus* (74.34%), *Acer* (9.88%), *Quercus* (9.10%), *Carpinus* (4.36%), *Populus* (0.51%)	Product of Ukraine	2" 1" ½"	57 514 1196
7	100% Natural Oak and Hickory	*Quercus* (Oak) (58.08%), *Carya* (Hickory) (8.46%) + *Juglans* (7.01%), *Pinus* (2.60%), *Ulmus* (0.95%), *Liquidambar* (0.71%), *Betula* (0.67%), *Acer* (0.58%), *Liriodendron* (0.36%), *Fagus* (0.31%), *Fraxinus* (0.20%), *Populus* (0.04%), *Tilia* (0.04%)	Made in USA	2" 1" ½"	50 633 1334
8	Oak and Hickory	*Quercus* (Oak) (56.58%), *Carya* (Hickory) (0.19%) + *Eucalyptus* (27.23%), *Pinus* (3.62%), *Maclura* (2.18%), *Juglans* (2.11%), *Ficus* (1.50%), *Neltuma* (1.48%), *Handroanthus* (0.29%), *Liquidambar* (0.10%)	Made in the USA	2" 1" ½"	23 180 308
9	One ingredient. Oak Hardwood	*Inga* (78.32%), *Curatella* (11.35%), *Hymenolobium* (3.17%), *Pistacia* (2.59%), *Albizia* (2.53%), Anacardiaceae (1.88%)	Not declared	2" 1" ½"	83 146 514
10	Natural Hardwood	*Neltuma* (40.03%), Unknown (29.49%), *Canotia* (8.56%), *Drypetes* (5.30%), *Manilkara* (5.14%), Fabaceae (3.12%), Anacardiaceae (3.00%), *Pistacia* (1.58%), *Lithraea* (0.89%), *Terminalia* (0.79%), Sapotaceae (0.51%), *Hippocratea* (0.05%)	Made in Mexico	2" 1" ½"	28 152 326
11	100% Organic Hardwood	*Neltuma* (59.21%), *Quercus* (25.06%), Celastraceae (4.03%), *Phyllostylon* (1.52%), *Tabernaemontana* (1.29%), *Drypetes* (1.16%), *Combretum* (0.97%), Anacardiaceae (0.88%), *Rhamnus* (0.78%), *Handroanthus* (0.73%), *Cordia* (0.61%), Tropical Fabaceae (0.54%), Sapotaceae (0.45%), *Pistacia* (0.40%), Sapindaceae (0.28%), *Lonchocarpus* (0.24%), *Ceanothus* (0.16%), *Diospyros* (0.04%)	Made in USA	2" 1" ½"	52 280 372
12	100% All Natural Hardwood	*Neltuma* (96.14%), *Magnolia* (0.09%)	Made in Mexico	2" 1" ½"	35 390 822
13	Oak, Hickory, Maple and other Hardwoods	*Quercus* (Oak) (69.47%), *Pinus* (8.09%), *Carya* (Hickory) (5.42%), *Liquidambar* (0.29%), *Fraxinus* (0.11%), *Juglans* (0.10%), *Platanus* (0.08%)	Made in America	2" 1" ½"	38 564 787

Table 3. Continued.

#	Claimed taxa	Observed taxonomic composition	Claimed origin	N each size class	
14	100% Natural Hardwood charcoal Sugar Maple	*Acer* (maple) (79.54%), *Betula* (7.15%), *Fagus* (0.55%), *Pinus* (0.17%), *Tilia* (0.15%)	Product of Canada	2"	45
				1"	450
				½"	1590
15	100% Mesquite charcoal	*Neltuma* (96.97%), Anacardiaceae (0.37%), Unknown (0.19%), *Pistacia* (0.16%), *Juglans* (0.06%), *Celtis* (0.03%), *Acer* (0.02%),	Product of Mexico	2"	26
				1"	101
				½"	251

Evaluation of claimed vs. observed charcoal taxonomic composition and origin

While the great majority of more than 18,000 wood fragments were identified at the genus level (over 86%), a small proportion (11.4%) could only be classified at the family level, and 2% remained unidentified (even though they were all determined to be tropical hardwoods) and were labeled as "unknown." This limitation highlights the challenges in identifying charcoal fragments at finer taxonomic levels, particularly for tropical taxa, as the charcoal production process alters the woods' original properties, making identification based on features like color, odor, density, or hardness impossible (Haag et al. 2020), and further induces changes in objective metrics due to differential shrinkage. Furthermore, smaller particles are much more difficult to identify than the larger pieces. This latter point is important for researchers with interest in evaluation claims by charcoal briquette manufacturers, as the individual charcoal particle sizes in briquettes are almost always of a size consistent with our "fines" category, and require substantially more effort to identify.

The claimed taxa and detailed taxonomic composition for each bag is shown in Table 3. A first point to highlight is the labeling ambiguity regarding claimed taxa. While approximately half of the bags specified one or more woody taxa, they often lacked explicit statements indicating that the product contained exclusively those taxa, potentially misleading consumers to reasonably infer that the listed taxa constitute the entirety of the product's composition.

With regard to product composition, our wood anatomical analysis revealed a remarkable diversity of species. We identified 29 different botanical families (Fig. 1) and 45 genera (Figs. 2–4). *Pinus* is the only softwood found in this study, but for bags claiming hardwoods-only (Bags # 7, 8, 13, 14), it represents a serious discrepancy. The most common hardwood families were Fabaceae and Fagaceae, which together made up roughly 65% of the charcoal we examined. This is considerably more diverse than the EU study by Haag et al. (2020), where 18 botanical families were found among 150 charcoal consignments. This difference could reflect differences in the EU and US, markets and/or source countries, and might also be influenced by the fact that our study identified roughly two and a half times as many charcoal fragments as Haag et al. (2020).

Quercus (28.39%) and *Neltuma* (19.23%) were the dominant genera, constituting approximately 48% of the sample. This finding aligns with both the information provided on packaging labels (Table 3) and a general understating of US lump charcoal consumer preferences. *Quercus* (oak) is prized for its slow-burning characteristics and the neutral flavor it imparts to grilled food, whereas *Neltuma* (mesquite) is sought for the distinctive smoky aroma attributed to it (Rozum, 2009, Husbands and Cranford 2019, Drobniak et al. 2021, Mencarelli et al. 2022). Interestingly, despite being listed on at least four bag labels (Table 3), *Acer* (maple) and *Carya* (hickory) represented only 6.7% and 1.8% of the total sample, respectively.

For a finer-grained analysis, bags were grouped based on taxonomic composition as a proxy for origin:

- temperate taxa only (five bags) (Fig. 2)
- mixed tropical and temperate taxa (six bags) (Fig. 3)
- tropical taxa only (four bags) (Fig. 4)

Table 4.—Weight accuracy assessment of commercial charcoal bags (to the nearest gram).

#	Claimed weight (g)	Measured weight (g)	Weight discrepancy (g)	MAV (g)	Disc. (g)/MAV (g)	Classification	Rank
1	9072	8882	189	140	1.35	Unreasonable deficit	2
2	9072	9082	−10	140	−0.07	Overage	1
3	9072	9402	−330	140	−2.36	Overage	1
4	9072	9062	10	140	0.07	Reasonable deficit	1
5	8165	7147	1018	140	7.27	Unreasonable deficit	7
6	7983	8215	−232	127	−1.82	Overage	1
7	9072	9183	−111	140	−0.79	Overage	1
8	3629	4301	−672	86	−7.82	Overage	1
9	7983	7580	403	127	3.17	Unreasonable deficit	4
10	4536	4542	−6	99	−0.06	Overage	1
11	9072	9097	−25	140	−0.18	Overage	1
12	9072	9003	68	140	0.49	Reasonable deficit	1
13	7003	7342	−338	127	−2.66	Overage	1
14	7983	7780	203	127	1.60	Unreasonable deficit	2
15	3629	3333	296	86	3.44	Unreasonable deficit	4

Claimed weight compared to the measured weight, with discrepancy calculated such that negative values indicate an overweight condition. Compliance with the Maximum Allowable Variations (MAV) as defined in NIST Handbook 133 is reported under "Classification" with a descriptor for whether overweight (cells not highlighted) reasonably underweight (cells highlighted in blue), or unreasonably underweight (cells highlighted in yellow), and a Rank column with an ordinal rank discretizing the discrepancy per Table 2.

Temperate-only bags.—Five bags (#1, 6, 7, 13, and 14) contained only temperate taxa (Table 3). In these cases, the declared origin (United States, Canada, Ukraine) was consistent with the observed taxa. However, out of the five bags, listed taxa and unlisted taxa from a similar forest type (i.e. north temperate) were found in four of them (#1, 7, 13, 14); that is, while the listed taxa were present, other taxa were also found that were not included in the declaration. Finally, in one bag (#6) the accuracy of the taxonomic claim was excessively broad, simply claiming "hardwood," which, while accurately reflecting its contents, is a comparatively low bar to meet.

Considering the distribution of taxa in the temperate-only bags, Figure 2 presents a predominance of *Quercus* (oak), which constituted 49.9% of the total composition. This result is consistent with labeling claims, which featured oak in three bags out of five (Table 3), and also with the results of Haag et al. (2020) for the EU market. Interestingly, *Carya* and *Liriodendron* (Fig. 2, and Fig. 2 legend) are members of the Arcto-Tertiary disjunct flora—these genera are part of north temperate forests in North America and Asia, but are absent from Europe, suggesting that such charcoal is more likely of North American origin than European or Asian origin.

Fraxinus (ash) emerged as an important fraction of the temperate-only group (17.31%) despite not being mentioned on any of the labels (Fig. 2, Table 3). This discrepancy raises concerns regarding the accuracy of labeling practices and the potential for taxon substitution or misidentification within the US lump charcoal market, though *Fraxinus* is consistent with a north temperate origin.

Temperate + tropical bags.—Six bags (#2, 5, 8, 11, 12, 15) contained a mix of temperate and tropical taxa, and of these, four (bags #2, 5, 12, 15) claimed to originate from Mexico and two (bags #8, 11) from the United States (Table 3). As one might expect, *Neltuma* (mesquite) emerged as the dominant taxon, representing 50.5% of the total weight (Fig. 3) in the temperate + tropical class. *Quercus* (oak) remained a major component (Fig. 3), although in a lower proportion (31.16%). Together, these two genera constituted over 80% of the total

Table 5.—Quantification of bark, fines, and rocks in charcoal samples and comparison to the maximum allowable variation (MAV).

#	Measured weight (grams)	MAV (grams)	Bark (grams)	Bark/MAV	Rock (grams)	Rocks/MAV	Fines (grams)	Fines/(MAV*2)	Proportion of usable content
1	8882	140	1707	12.19	0	0.00	730	2.61	0.726
2	9082	140	1989	14.21	115	0.82	416	1.49	0.722
3	9402	140	264	1.89	0	0.00	687	2.45	0.899
4	9062	140	110	0.78	0	0.00	240	0.86	0.961
5	7147	127	229	1.80	0	0.00	1294	5.09	0.787
6	8215	140	140	1.00	0	0.00	301	1.08	0.946
7	9183	140	1846	13.19	8	0.05	453	1.62	0.749
8	4301	99	189	1.91	0	0.00	268	1.35	0.894
9	7580	127	12	0.09	0	0.00	556	2.19	0.925
10	4542	99	65	0.65	0	0.00	180	0.91	0.946
11	9097	140	633	4.52	12	0.09	316	1.13	0.894
12	9003	140	225	1.61	79	0.56	758	2.71	0.882
13	7342	127	1130	8.90	11	0.09	408	1.61	0.789
14	7780	127	860	6.77	18	0.15	673	2.65	0.801
15	3333	86	69	0.80	0	0.00	200	1.16	0.919

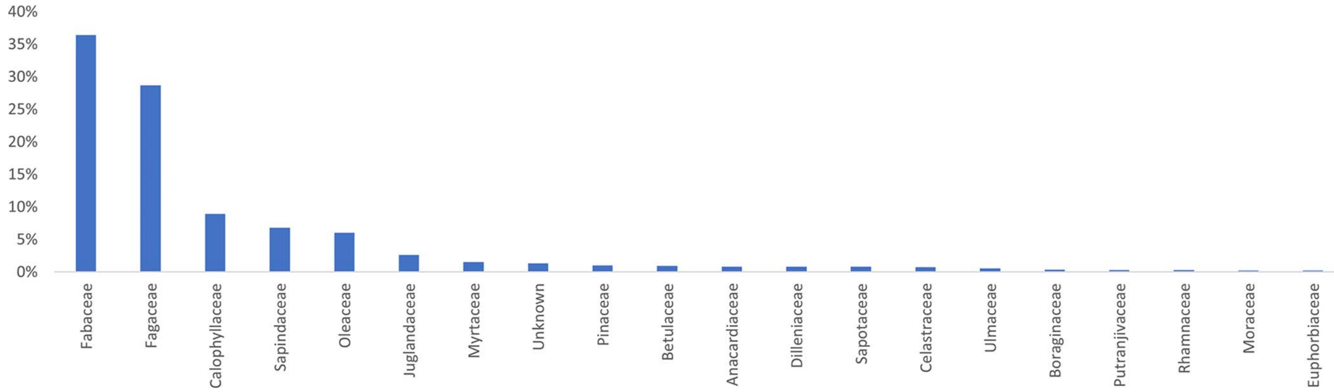

Figure 1.—Family-level identification of charcoal fragments across all bags. Bars represent the percentage of total charcoal weight attributed to each family. Not displayed are families representing less than 0.1% of the total (Apocynaceae, Altingiaceae, Combretaceae, Bignoniaceae, Salicaceae, Magnoliaceae, Malvaceae, Platanaceae, Ebenaceae, and Cannabaceae). The top seven families represent 91.02%.

charcoal weight among these six bags. Bag #2 claimed to contain "oak" with no other botanical claims made. Upon examination, *Quercus* comprised 74.6% of the bag, and the rest consisted of *Neltuma* (0.1%) and Anacardiaceae at approximately 0.9%.

Bag #5, claiming "100% natural hardwood" and "from renewable natural resources," contained at least 18 different taxa. The most abundant genera identified were *Neltuma* (31.55%), followed by unidentified members of Fabaceae (14.84%), *Albizia* (8.97%), Sapotaceae (7.89%), *Eucalyptus* (7.06%), *Ulmus* (6.69%), and *Cordia* (5.59%). The mix also included Euphorbiaceae (3.90%), *Rhamnus* (1.77%), *Ceanothus* (1.52%), and *Ficus* (1.40%); *Quercus*, *Pistacia*, *Xerospermum*, Anacardiaceae, *Fraxinus*, *Castanea*, and Sapindaceae all at less than 1.0% composition; and a variety of other tropical hardwoods (totaling an additional 2.38%) that could not be identified at the family level. This bag claims to use "renewable natural resources," presumably seeking to imply responsible forest management. However, all wood and wood-derived materials are technically renewable, even when harvested irresponsibly. The bag contained a variety of taxa from different forest types, strongly suggesting that the content comes from multiple sources, not all of which necessarily within Mexico.

Bag #12, claiming "hardwood," contained 96.14% *Neltuma* (mesquite) and 0.09% *Magnolia*, both of which are hardwoods and thus consistent with the overly broad claim. Bag #15 claimed 100% mesquite, which is consistent with the country's typical hardwood taxa used for charcoal (Taylor 2008). Our analysis revealed approximately 97% *Neltuma* (mesquite) with the remaining percentage comprising other taxa such as Anacardiaceae (0.37%), unknown tropical hardwood (0.19%), *Pistacia* (0.16%), *Juglans* (0.06%), *Celtis* (0.03%), and *Acer* (0.02%). While the dominant taxa align with the expected composition, the presence of other taxa in small amounts is noteworthy.

Bags #8 and 11 contained temperate taxa mixed with tropical taxa that are not typically found in the United States (Table 3), suggesting that the raw materials were likely sourced elsewhere, potentially Mexico, despite the "Made in USA" label. Bag #8 claimed to contain oak and hickory, but analysis revealed the presence of multiple taxa, with oak comprising 56.58% and hickory only 0.19% by weight, and the remaining weight made up of *Eucalyptus* (27.23%), *Pinus* (3.62%), *Maclura* (2.18%), *Juglans* (2.11%), *Ficus* (1.50%), *Neltuma* (1.48%), *Handroanthus* (0.29%), and *Liquidambar* (0.10%). Bag (#11) was labeled as "100% organic hardwood." As previously discussed, the term "organic" in this context is problematic. Analysis revealed a composition of *Neltuma* (59.21%), *Quercus* (25.06%), and a mix of tropical taxa.

The Federal Trade Commission's (FTC) "Made in USA" standard requires that all or virtually all significant parts,

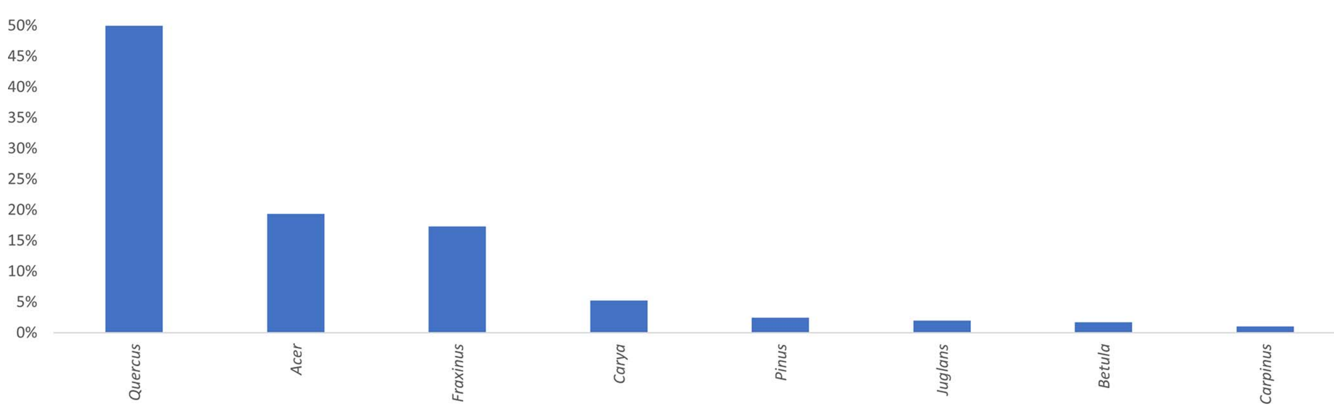

*Figure 2.—Genus-level distribution of charcoal fragments found in bags containing exclusively temperate hardwoods. Bars represent the percentage of total charcoal weight attributed to each genus. Not displayed are genera representing less than 1% of the total (*Ulmus, Liquidambar, Fagus, Populus, Liriodendron, Tilia, Alnus, *and* Platanus*). The top seven genera represent 97.9% of the charcoal identified in temperate-only contents, by weight.*

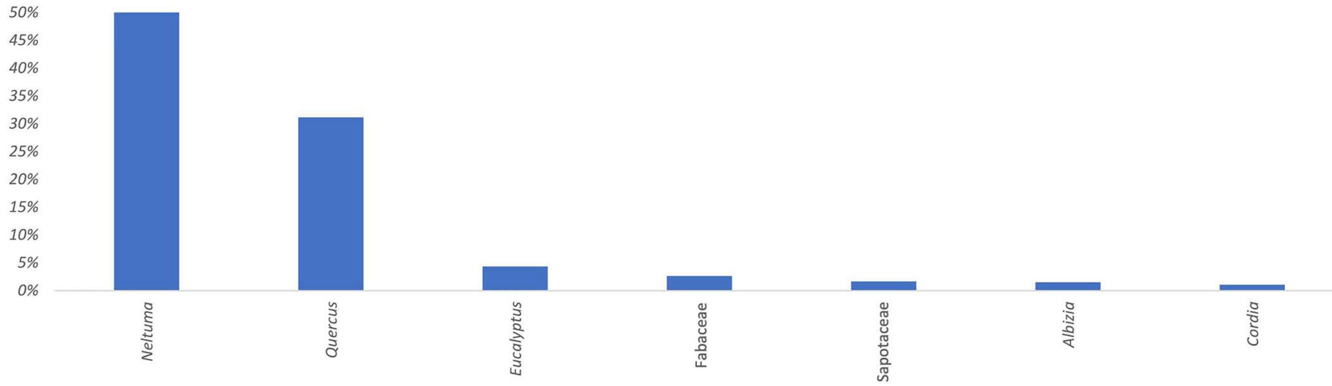

Figure 3.—Genus-level distribution of charcoal fragments found in bags containing mixed temperate and tropical hardwoods. Bars represent the percentage of total charcoal weight attributed to each genus/family. Not displayed are genera representing less than 1% of the total (Celastraceae, Ulmus, *Euphorbiaceae, Anacardiaceae,* Rhamnus, Pinus, Ficus, Phyllostylon, Tabernaemontana, Ceanothus, Drypetes, Maclura, Juglans, *Unknown,* Combretum, Pistacia, Handroanthus, Xerospermum, *Sapindaceae,* Lonchocarpus, Fraxinus, Carya, Magnolia, Liquidambar, Castanea, Diospyros, Celtis, *and* Acer*). The top seven genera represent 92.8% of the temperate + tropical contents by weight.*

processing, and labor be of US origin, with final assembly or processing occurring in the United States. Products may be considered "Made in the USA" even if the raw material is foreign, provided they undergo a "substantial transformation" in the United States. However, the term "substantial transformation" might be problematic in application to charcoal because, while the conversion of wood to charcoal involves a major transformation, the final product's essential character and value are still derived from the original wood. This ambiguity in applying the "substantial transformation" rule calls for greater clarity to avoid misleading consumers; using a qualified claim such as "Made in USA from imported wood" would provide a more accurate representation of the charcoal's origin and manufacturing process.

Tropical-only bags.—The analysis of the four charcoal bags containing exclusively tropical hardwoods (#3, 4, 9, 10), reveals intriguing insights into the composition and potential mislabeling of charcoal within the US market, with implications for both consumer transparency and conservation efforts.

Aspidosperma, a tropical genus, emerged as the dominant constituent comprising approximately 30% of the total weight (Fig. 4). Another substantial portion (30%) of the analyzed fragments were identified as belonging to the Fabaceae, appearing most similar to *Anadenanthera* (Fig. 4). *Inga* appeared as the third most common taxon, contributing to 19% of the total weight (Fig. 4). *Aspidosperma* was present exclusively in the bag originating from Paraguay (#4) and absent in all other samples. *Anadenanthera* was exclusively present in the bag from Brazil (bag#3, Table 3). Interestingly, these bags exhibited a unique homogeneity, each containing only the mentioned taxa.

The remaining two bags presented a contrasting picture in terms of transparency of product claim. While one (# 10) declared Mexico as its country of origin and contained a mix of tropical taxa consistent with that country, the other (# 9) lacked any origin information on the package (but online investigation of the product SKU indicated an El Salvador origin) and was misleadingly labeled as "One ingredient Oak hardwood" (Table 3). Analysis of the latter bag revealed the presence of at least six different taxa (Table 3) and a complete absence of oak (*Quercus*), further highlighting the issue of fraud and misrepresentation in the charcoal market. The lack of transparency observed in the labeling of charcoal products raises concerns regarding the accuracy of information provided to consumers.

While none of the genera identified in our study were listed under the Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES) at the time of

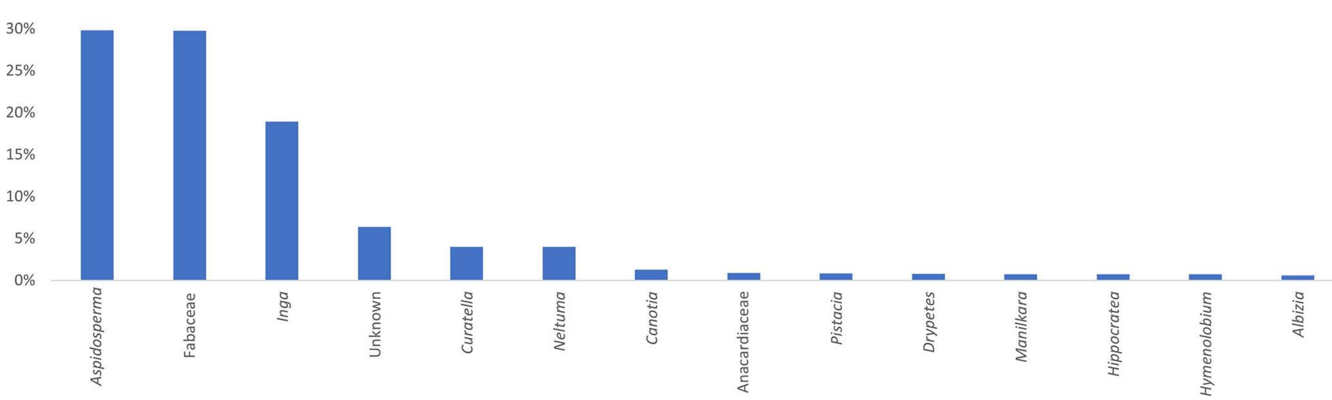

*Figure 4.—Genus-level distribution of charcoal found in bags containing exclusively tropical hardwoods. Bars represent the percentage of total charcoal weight attributed to each genus/family. Not displayed are genera representing less than 0.1% of the total (*Lithraea, Terminalia, *and Sapotaceae). The top six genera represent 92.9% in the tropical-only bags, by weight.*

purchase, the presence of taxa such as *Inga*, *Pistacia*, *Drypetes*, *Manilkara*, *Hymenolobium*, *Handroanthus*, *Albizia*, *Terminalia*, and *Neltuma*, which include taxa classified as Near Threatened (NT), Vulnerable (VU), Endangered (EN), and Critically Endangered (CR) on the IUCN Red List (IUCN 2024), highlights the potential for unsustainable harvesting practices and underscores the need for greater vigilance and responsible sourcing within the US lump charcoal market.

Taxonomic distribution by size class

The taxonomic distribution within different charcoal lump size classes (2-inch, 1-inch, and half-inch) was analyzed for temperate, mixed, and tropical taxa across all bags.

Temperate-only bags.—The taxa distribution across the three size classes showed distinct patterns. *Quercus* was consistently dominant in all size classes, representing the largest proportion by weight (51%, 50%, and 48% for 2-inch, 1-inch, and half-inch, respectively). *Acer* maintained a relatively consistent presence across all size classes (17%, 20%, and 19%), while *Fraxinus* showed a decreasing trend with decreasing fragment size (25%, 16%, and 11%). *Carya* was more abundant in the smaller size classes. Several taxa including *Ulmus*, *Liquidambar*, *Liriodendron*, *Populus*, *Tilia*, *Platanus*, *Juglans,* and *Alnus* were absent in the 2-inch size class but appeared in small amounts in the half-inch class. *Juglans* exhibited a particularly high proportion in the half-inch class (Fig. 5). Overall, this distribution suggests that roughly half of the taxa were consistently present across all size classes. The remaining 44% constituted the 1-inch and half-inch classes, and just 6% were found only in the 1-inch class.

Temperate + tropical bags.—*Neltuma* was the most abundant taxon across all size classes and increased in representation as fragment size decreased (46%, 51%, and 61% for 2-inch, 1-inch, and half-inch, respectively). *Quercus* followed as the second most abundant taxon, showing a decreasing trend (33%, 31%, and 24%). All other taxa represented less than 10% in one or more size classes, with Fabaceae, *Albizia*, and *Cordia* being more prominent in the 2-inch class (5.7%, 3.2%, 2.4%). A mix of temperate and tropical taxa such as *Phyllostylon, Tabernaemontana, Ceanothus, Maclura, Pistacia, Handroanthus, Xerospermum,* Sapindaceae, *Lonchocarpus, Fraxinus, Magnolia, Carya, Liquidambar, Castanea, Diospyros, Celtis,* and *Acer* were not present in the 2-inch size but were present in small amounts in the 1-inch and half-inch classes (Fig. 6, and data not shown). Comparing this temperate + tropical mixed group with the temperate-only bags, we find roughly half of the taxa represented across all the three size classes. However, the distribution of the remaining half diverges substantially from the temperate-only bags. Specifically, 8% are found exclusively in the 1-inch size class, and 25% are found in both the 1-inch and half-inch classes. A substantial 17% of taxa are observed only in the smallest half-inch size class. This pattern, particularly the increased prevalence of taxa solely in the half-inch class, becomes intriguing when contrasted with the temperate-only charcoal where all the taxa found in the half-inch class were also found in other size classes. This pronounced prevalence of mixed temperate and tropical taxa in the smallest size classes suggest that these taxa might have been intentionally included as smaller pieces in the charcoal blend to meet the claimed net weight

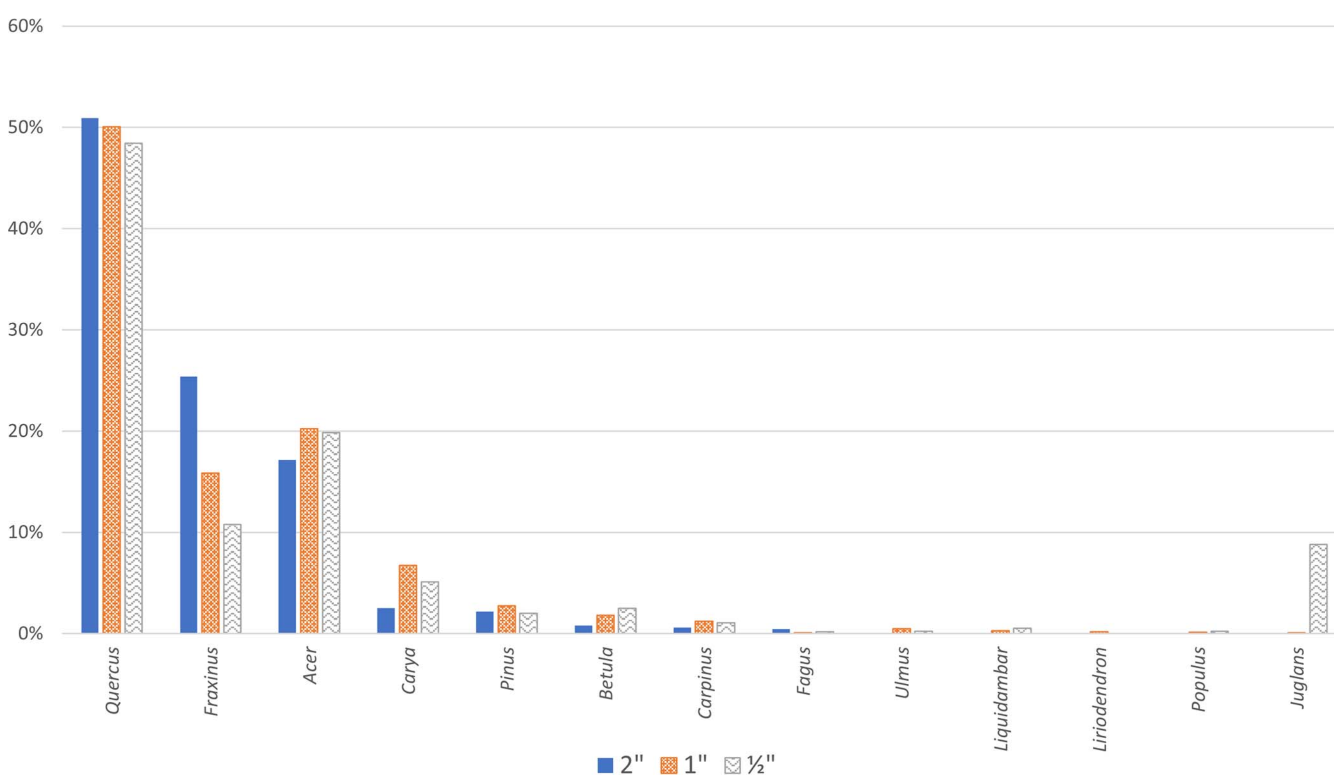

*Figure 5.—Breakdown of the taxonomic composition by size class (2-inch, 1-inch, and 1/2-inch) of exclusively temperate bags. Taxa are sorted by proportion of 2″ material, then by proportion of 1″ material, then by proportion of ½″ material. Taxa representing less than 0.06% of the total charcoal weight are not shown (*Tilia, Platanus, *and* Alnus*).*

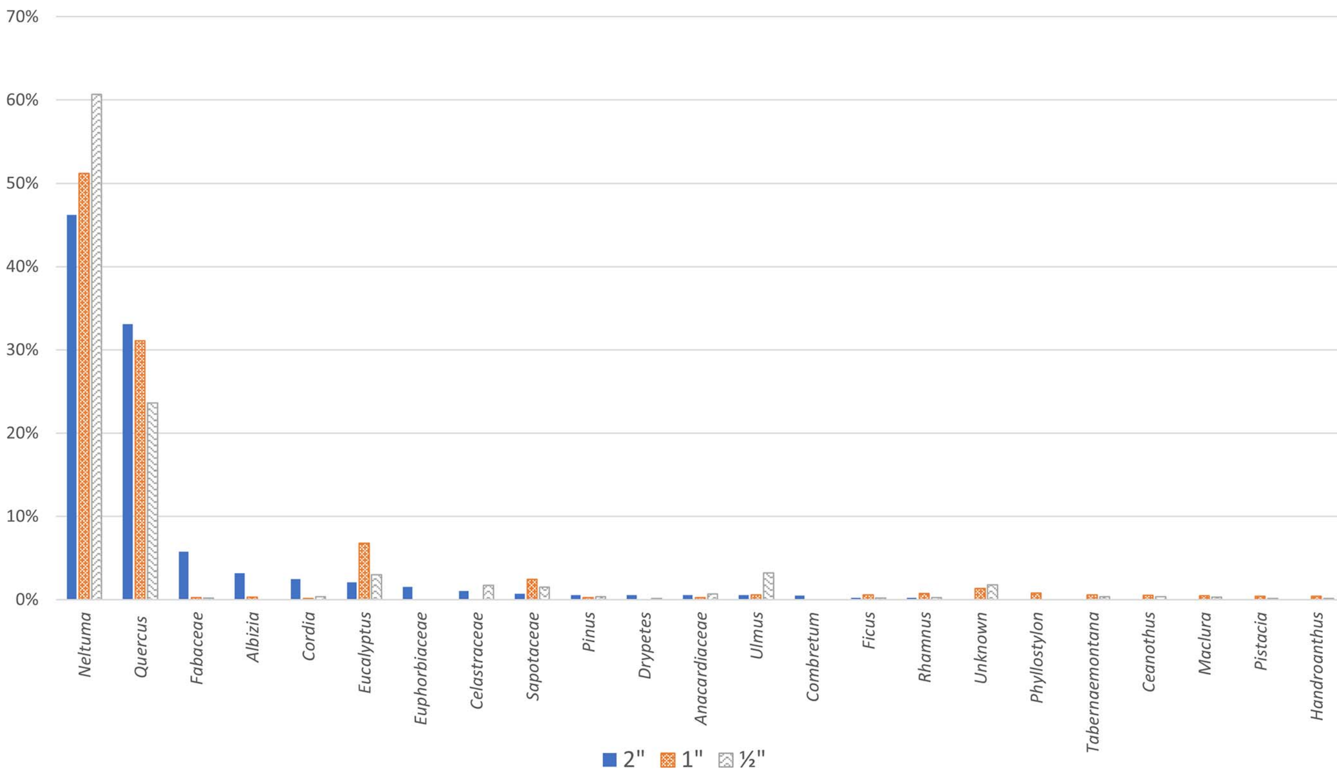

*Figure 6.—Breakdown of the taxonomic composition by size class (2-inch, 1-inch, and 1/2-inch) of temperate + tropical hardwood bags. Taxa are sorted by proportion of 2″ material, then by proportion of 1″ material, then by proportion of ½″ material. Taxa representing less than 0.1% of the total charcoal weight are not shown (*Xerospermum, *Sapindaceae,* Lonchocarpus, Fraxinus, Carya, Magnolia, Liquidambar, Castanea, Diospyros, Celtis, *and* Acer*).*

and, as such, could represent a separately sourced charcoal supply.

Tropical-only bags.—Fabaceae exhibited a consistent presence across all size categories, though its relative abundance varied (34%, 22%, and 40% for 2-inch, 1-inch, and half-inch, respectively). *Inga* showed a decreasing trend with decreasing fragment size (25%, 12%, and 13%), while *Aspidosperma* demonstrated a contrasting pattern, with its highest representation in the 1-inch category (44%). *Neltuma* was more abundant in the smaller size categories (Fig. 7). Approximately 70% of the sixteen taxa analyzed including the unidentified fragments were present across all three size classes. The remaining 30% displayed a more limited size range, with 12% found exclusively in the 1-inch size class. Another 6% were present in both the 1-inch and half-inch classes. Finally, 12% were found solely in the half-inch size class. This difference in taxonomic distribution by size class reinforces the possibility of intentional blending practices to meet the claimed net weight.

Bag weight claims

An assessment of the charcoal bags revealed a substantial discrepancy between the measured weight and the claimed net weight declared on the packaging (Table 4). Forty-seven percent of the bags (seven in total) were found to be underweight (# 1, 4, 5, 9, 12, 14, and 15). The degree of underloading varied considerably, ranging from 0.1% to 12.5% of the total claimed weight. Five of these bags (# 1, 5, 9, 14, and 15) fell outside the acceptable range for weight variation as defined by NIST Handbook 133, indicating a potential violation of fair trade practices. This discrepancy ranged from 1.35 (#1) to 7.27 (#5) times the maximum allowable variation (MAV).

Lump size screening

While not an explicitly evaluable claim based on information on packaging, we determined the mass of of charcoal fragments in each of four size classes: fines ($<$ 0.5 inches), half-inch, 1-inch, and 2-inch fragments, as defined in the Materials and Methods. The weight of each size class was measured, along with the total measured weight and the claimed weight as stated on the bag. Figure 8 presents these data, with bar length representing the total weight and black circles indicating the claimed weight.

Lump size is a crucial factor for charcoal consumers as it greatly influences burning characteristics, wherein larger lumps typically burn hotter and longer, making them ideal for grilling thicker cuts of meat or for recipes requiring high heat (CEN EN 1860-2:2005 n.d.). Conversely, smaller pieces ignite more quickly and burn at a lower temperature, making them suitable for faster cooking or situations where lower heat is desired (CEN EN 1860-2:2005 n.d.). Therefore, the distribution of lump sizes within a bag of charcoal can affect its overall performance and suitability for different grilling needs, and while not necessarily a common practice, larger pieces can always be broken into smaller fragments by the user, but smaller fragments cannot be formed by the user into larger pieces.

As seen in Figure 8, some bags exhibit a relatively even distribution across the size classes, while others show a

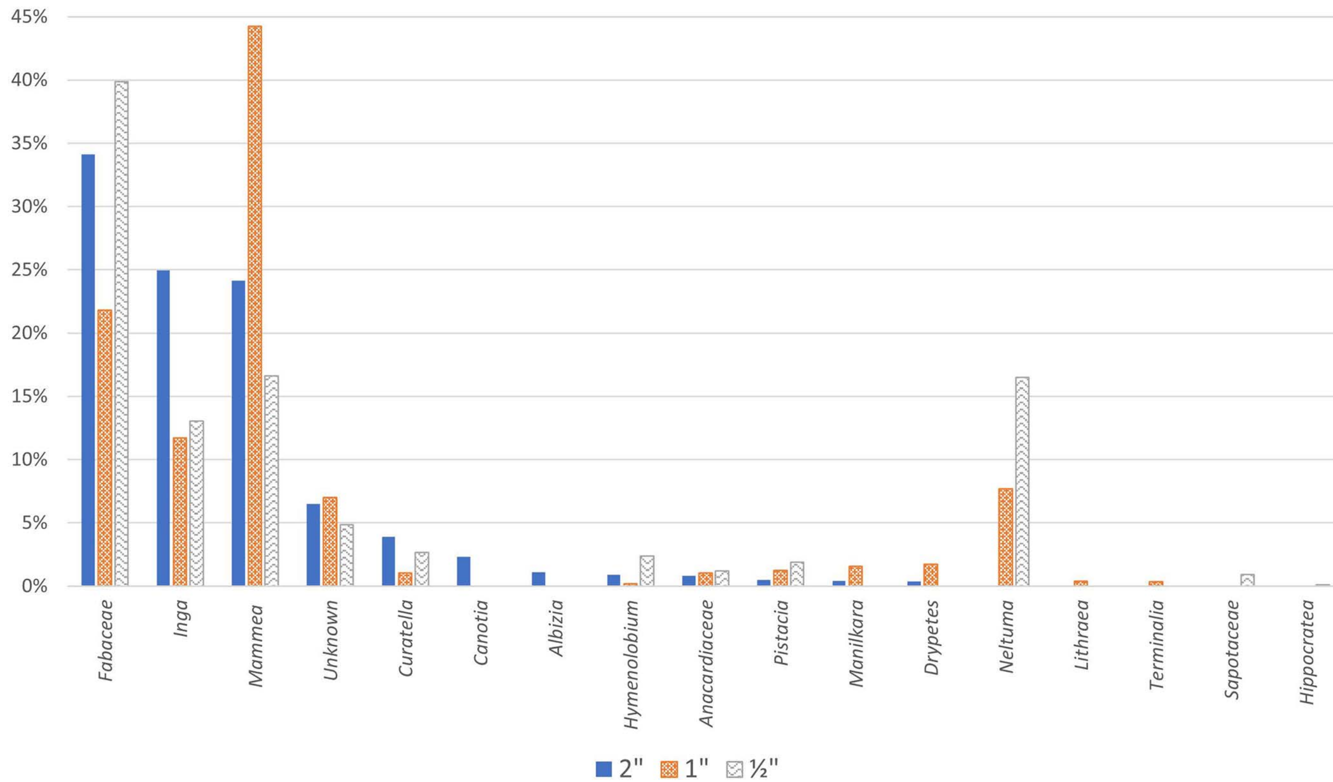

Figure 7.—Breakdown of the taxonomic composition by size class (2-inch, 1-inch, and 1/2-inch) of exclusively tropical bags. Taxa are sorted by proportion of 2-inch material, then by proportion of 1-inch material, then by proportion of half-inch material.

higher proportion of fines or a dominance of larger lumps. This heterogeneity may be attributed to several factors, including the inherent mechanical strength of the charcoal, which can vary dramatically between woody taxa; handling and transportation methods, where rough practices can lead to fragmentation and an increase in fines; intentional blending by manufacturers to achieve desired burning characteristics or to meet weight specifications; and, to some extent, our sifting protocol that doubtless produced some shifts toward a larger weight of fines and smaller particles.

Presence of extraneous material

A last factor we include is the determination of the mass of extraneous materials—those either not combustible (rocks); undersized for use in a charcoal grill (fines, or dust and those pieces that passed through a half-inch mesh); or pieces of charred material that are not botanically wood (e.g., bark)—in their varying proportions across the bags (Fig. 9).

Bark was found in every bag (Fig. 9), constituting between 0.2% and 22% of the total weight. Notably, 10 bags exceeded the MAV for bark content. Of these, three bags (#1, 2, and 7) contained over 10 times the MAV for bark (Table 5), and only five bags had a bark content less than 1 MAV.

Fines were also present in all bags, comprising between 2.7% and 18% of the total weight (Fig. 9). However, it is important to consider that our sifting method may have increased the proportion of fines compared to what a consumer would typically find in a bag. To account for this potential increase, we created a "Fines/(MAV*2)" index, which generously assumes that our sifting process could have doubled the weight of fines. Even with this charitable metric, 13 of the 15 bags exceeded the doubled MAV for fines content (Table 5), with bag #5 exceeding that value five-fold (Table 5). Rocks, while less prevalent than fines, were detected in six bags, comprising up to 1.3% of their weight, but none of the bags exceeded the MAV for rocks (Table 5). When all extraneous materials were considered *en masse* as a single group, all 15 bags exceeded the MAV, ranging from ~1.56 times to ~16.52 times the MAV.

The discrepancy between the claimed net weight and the actual weight of usable charcoal combined with the presence of extraneous materials such as bark, fines, and rocks in lump charcoal products raises concerns about the quality and value of these charcoal products. Presence of these materials does not contribute to the combustion process (at all in the case of rocks, and not at the same temperature and rate for fines and bark) and they reduce the relative proportion of usable charcoal, potentially deceiving consumers who are essentially paying for nonfunctional components. While the inherent comparative fragility of charcoal can lead to fragmentation during handling and transport, explaining the presence of some fines, it does not justify the inclusion of bark and rocks.

Summary of fraud and misrepresentation in the US lump charcoal market

Our snapshot-in-time data reveal inconsistencies in product labeling and composition in the US lump charcoal market. These discrepancies raise questions about the transparency and reliability of information presented to consumers, potentially impacting their purchasing decisions and grilling experience. Figure 10 provides a visual summary of our findings, illustrating

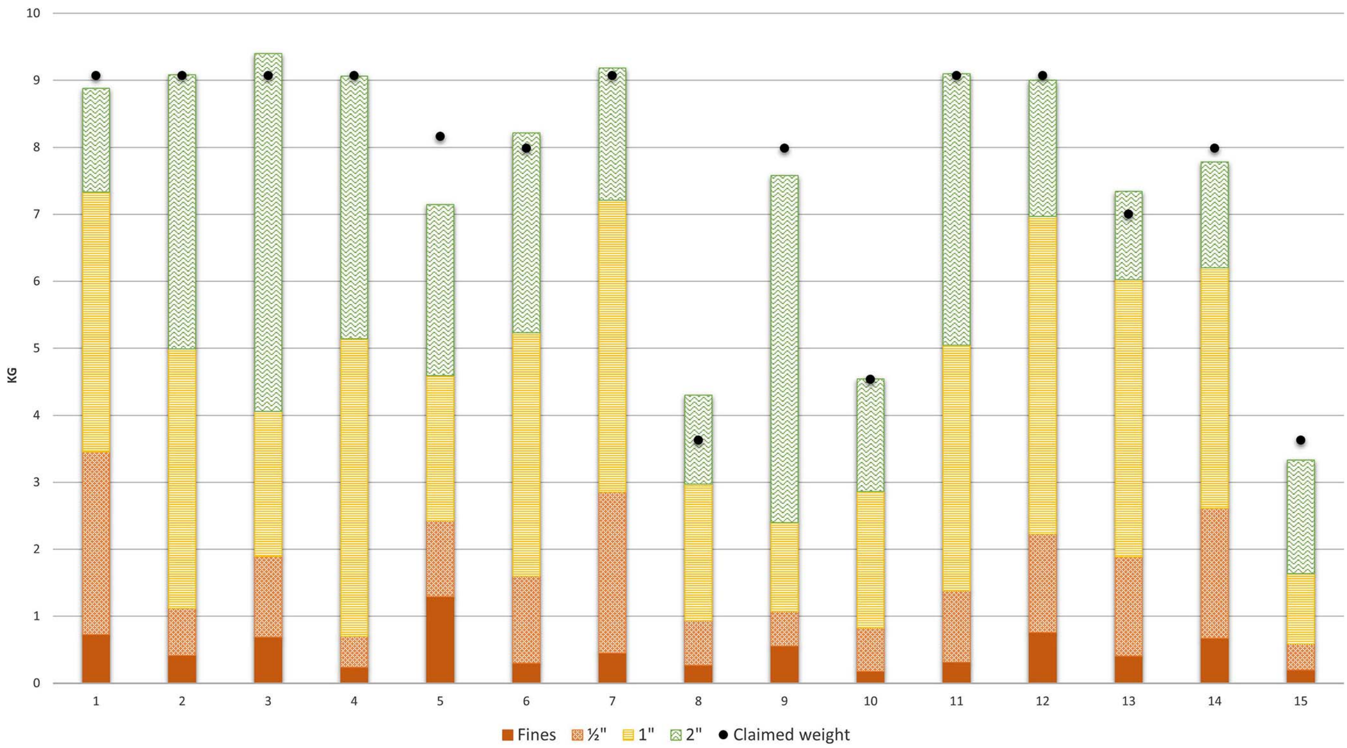

Figure 8.—Analysis of charcoal lump size distribution in 15 commercial bags. Each bar represents the total weight of the bag, broken down by size class: fines (<0.5 inches), 1/2-inch, 1-inch, and 2-inch, from bottom to top, respectively. Black circles indicate the claimed weight on the packaging.

the accuracy of product claims across three critical categories: taxonomic claim, origin claim, and weight (mass) claim. To quantify these inconsistencies, we developed an ordinal discretization method, detailed in Table 2, where higher ranks indicate greater deviations from the label claims.

Our findings suggest a relationship between charcoal "source" and labeling accuracy. Bags containing exclusively temperate taxa (blue data points in Fig. 10) generally exhibit greater accuracy in taxonomic and origin claims, although weight discrepancies were still observed. Bags containing exclusively tropical taxa (orange data points) were penalized more for broad taxonomic claims than for mislabeling—their product claims were so broad as to claim very little (e.g., "hardwood"). Conversely, products containing a mixture of

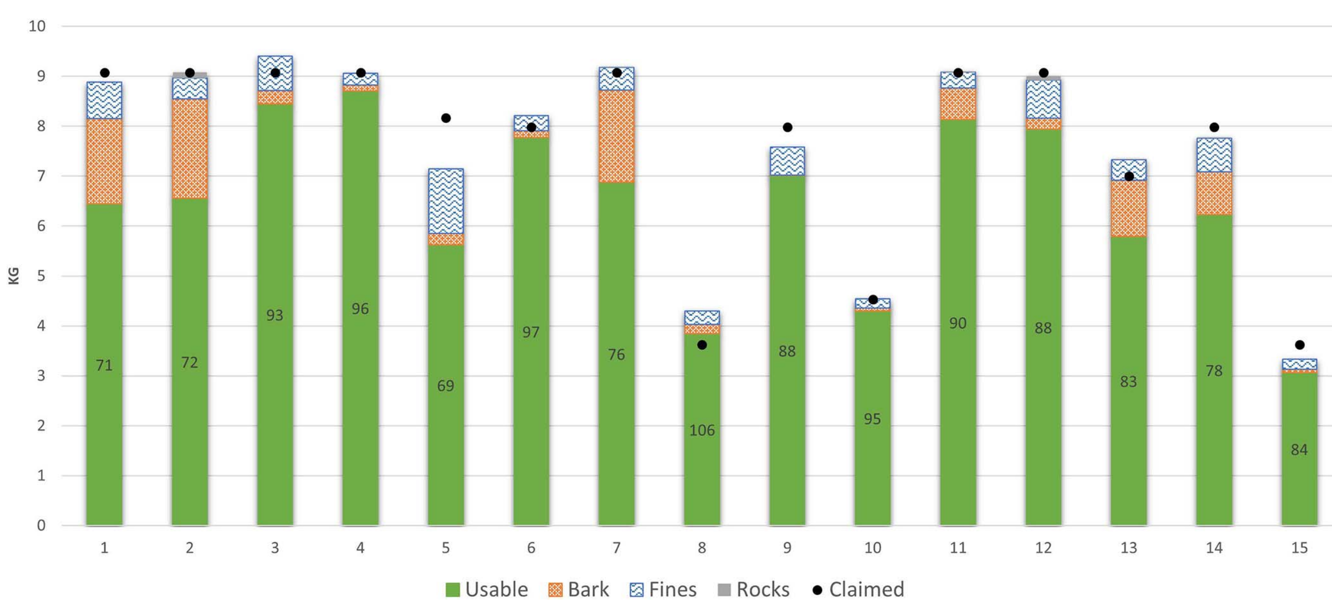

Figure 9.—Analysis of the weight of charcoal and extraneous materials per bag. The figure shows the proportion of charcoal fragments over ½ inch (noted as usable), bark, fines, and rocks (from bottom to top, respectively) in each bag. The black circles represent the claimed weight, while the total bar length represents the measured weight. Percentages (numeric values reported in the green bars) of usable charcoal fragments over ½ inch are calculated based on the claimed weight.

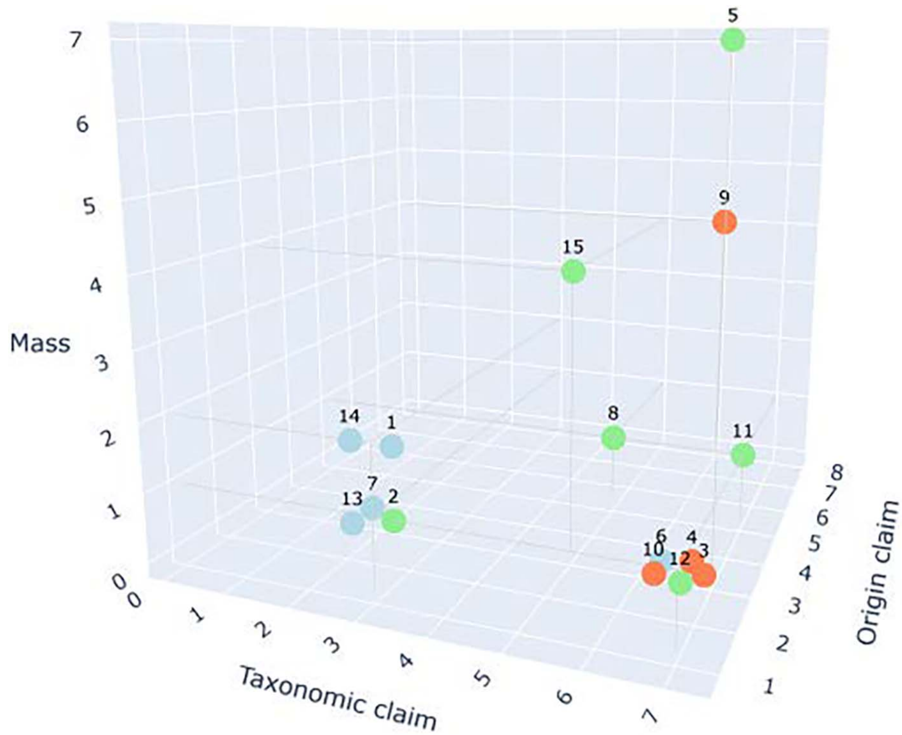

Figure 10.—Accuracy of product claims across three categories: taxonomic claim, origin claim, and mass claim. Blue data points are bags containing exclusively temperate woody taxa, green data points are bags containing temperate and tropical mixed taxa, and orange data points are bags containing exclusively tropical taxa.

temperate and tropical species (green data points) tended to display the most problematic labeling practices, with a higher frequency of inaccuracies regarding taxonomic, origin, and weight claims.

These findings have important implications for consumer value and market transparency. Inaccurate weight claims directly impact the economic value consumers receive, as underloaded bags fail to deliver the expected quantity of product. Furthermore, discrepancies in taxa and origin labeling not only mislead consumers regarding product composition and sourcing but may also impact the grilling experience. For instance, charcoal made from different wood types burn at different temperatures, for different durations, and are thought to impart distinct flavors to food. The prevalence of vague labeling practices, such as the generic term "hardwoods," further exacerbates the issue by precluding informed consumer choice based on specific wood preferences or desired grilling outcomes. Overall, these results align with concerns raised by a study in the EU. (Haag et al. 2020) and within the broader US forest products sector (Wiedenhoeft et al. 2019), confirming that misrepresentation is a substantial concern within the context of US lump charcoal. Our study cannot purport to address how to ameliorate such misrepresentation in the market, but awareness of the problem in the supply chain is a first necessary step toward improved transparency and accuracy.

Conclusion

Our analysis reveals discrepancies between the claimed taxa, origin, and weight of lump charcoal sold in the US market and the actual composition of these products, which corroborates previous findings of misrepresentation in the US forest products supply chain and the EU charcoal trade. While this investigation provides a first snapshot-in-time for lump charcoal in the US market, further research would be valuable to assess if currently available lump charcoal still evinces such misrepresentations. Such research should ideally include expanding the scope of analysis to other charcoal products, especially charcoal briquettes, and investigating more deeply the complex issues surrounding charcoal production, consumption, and trans-national supply chains.

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Literature Cited

AMS. 2000. National Organic Program: Final Rule with request for comments (7 CFR Part 205). Agricultural Marketing Service, National Organic Program, US Department of Agriculture, Washington, DC. Accessed November 8, 2024.

Ang, T. Z., M. Salem, M. Kamarol, H. S. Das, M. A. Nazari, and N. Prabaharan. 2022. A comprehensive study of renewable energy sources: classifications, challenges and suggestions. *Energy Strategy Rev* 43:100939
Angeles, G. 2001. New techniques for the anatomical study of charcoalified wood. *IAWA* J22(3):245–254.
Bays, H. C. M., M. C. Bolding, J. L. Conrad, H. L. Munro, S. M. Barrett, and A. Peduzzi. 2024. Assessing the sustainability of forest biomass harvesting practices in the southeastern US to meet European renewable energy goals. *Biomass Bioenergy* 186:107267.
Braga Júnior, M. M., F. I. B. de Souza, and L. E. de L. Melo. 2021. Forestry control in the Brazilian Amazon II: charcoal anatomy of 21 species. *IAWA J.* 42(3):299–321.
CEN 1860-2:2005. N.d. Appliances, solid fuels and firelighters for barbecuing—part 2: barbecue charcoal and barbecue charcoal briquettes—requirements and test methods.
Chidumayo, E. N. and D. J. Gumbo. 2013. The environmental impacts of charcoal production in tropical ecosystems of the world: A synthesis. *Energy Sustain Dev* 17(2):86–94.
Da Ponte, E., M. Roch, P. Leinenkugel, S. Dech, and C. Kuenzer. 2017. Paraguay's Atlantic Forest cover loss–Satellite-based change detection and fragmentation analysis between 2003 and 2013. *Appl Geogr* 79:37–49.
da Silva, A. A., K. C. de Sousa, F. I. B. de Souza, J. R. C. Nobre, T. de, P. Protásio, and L. E. de L. Melo. 2024. Forestry control in the Brazilian Amazon III: anatomy of wood and charcoal of tree species from sustainable forest management. *IAWA J* 45(3):1–38.
de Freitas Netto, S. V., M. F. F. Sobral, A. R. B. Ribeiro, and G. R. D. L. Soares. 2020. Concepts and forms of greenwashing: A systematic review. *Environm Sci Europe* 32:1–12.
Dias, E. C., A. Á. Assunção, C. B. Guerra, and H. A. Cano Prais. 2002. Labor process and workers' health in charcoal production in Minas Gerais, Brazil. *Cadernos de Saúde Pública* 18:269–277. (In Portuguese with English summary).
Dittmar, H. 2024. Environmental crimes in the Brazilian native charcoal production chain. *Revista Cient. Multidiscip* 5:1–16.
Drobniak, A., Z. Jelonek, M. Mastalerz, and I. Jelonek. 2021. Atlas of charcoal-based grilling fuel components. *Indian J. Earth Sci* 3. https://doi.org/10.14434/ijes.v3i1.32559
Easterly, J. L. and M. Burnham. 1996. Overview of biomass and waste fuel resources for power production. *Biomass Bioenerg* 10(2–3):79–92.
Fenton, M. C. 2024. Deforestation in Paraguay and the Impacts of the Zero Deforestation Law (Doctoral dissertation, University of California, Davis).
García-Quezada, J., R. Musule-Lagunes, J. A. Prieto-Ruíz, D. J. Vega-Nieva, and A. Carrillo-Parra. 2022. Evaluation of four types of kilns used to produce charcoal from several tree species in Mexico. *Energies* 16(1):333.
Gonçalves, T. A., S. Nisgoski, J. S. Oliveira, C. R. Marcati, A. W. Ballarin, and G. I. Muniz. 2016. A contribution to the identification of charcoal origin in Brazil II-Macroscopic characterization of Cerrado species. *An Acad Bras Cienc* 88(02):1045–1054.
Haag, V., V. T. Zemke, T. Lewandrowski, J. Zahnen, P. Hirschberger, U. Bick, and G. Koch. 2020. The European charcoal trade. *IAWA J* 41(4):463–477.
Hall, J. P. 2002. Sustainable production of forest biomass for energy. *Forest Chron* 78(3):391–396.
Husbands, A. and S. Cranford. 2019. A material perspective of wood, smoke, and BBQ. *Matter* 1(5):1092–1095.
IEA Bioenergy. 2024. Annual Report 2023. IEA Bioenergy. https://www.ieabioenergy.com/wp-content/uploads/2024/06/Annual-Report-2023.pdf (Accessed April 16, 2025).
Interpol. 2015. Environmental crime and its convergence with other serious crimes. Interpol, Lyon. https://www.interpol.int/content/download/5086/file/INTERPOL%20Strategic%20Report%20-%20Environmental%20Crime%20and%20its%20Convergence%20with%20other%20Serious%20Crimes.pdf. Accessed August 8, 2024.
IUCN. 2024. The IUCN Red List of Threatened Species. Version 2024-2. https://www.iucnredlist.org. Accessed February 12, 2025.
Kabir, E., K. H. Kim, J. W. Ahn, O. F. Hong, and J. R. Sohn. 2010. Barbecue charcoal combustion as a potential source of aromatic volatile organic compounds and carbonyls. *J Hazard Mater* 174(1–3):492–499.
Magrath, W., P. Younger, H. Phan. 2010. Chainsaw project. An Interpol perspective on law enforcement in illegal logging. The World Bank and Interpol, Washington D.C. http://www.redd-monitor.org/wp-content/uploads/2011/10/WorldBankChainsawIllegalLoggingReport1.pdf
Mencarelli, A., D. Stare, S. Grigolato, R. Greco, and M. Triplat. 2025. A 4-year assessment of the qualitative characteristics of Slovenian barbecue lump charcoal and its compliance with the EN 1860-2 standard. Eur J Wood Wood Prod 83(1):1–12.
Mencarelli, A., R. Cavalli, and R. Greco. 2022. Variability on the energy properties of charcoal and charcoal briquettes for barbecue. *Heliyon* 8(8):e10052.
Mencarelli, A., R. Greco, S. Balzan, S. Grigolato, and R. Cavalli. 2023. Charcoal-based products combustion: emission profiles, health exposure, and mitigation strategies. Environmental Advances, 13, p. 100420.
Nellemann C., R. Henriksen, R. Pravettoni, D. Stewart, M. Kotsovou, M. A. J. Schlingemann, M. Shaw, and T. Reitano (Eds.). 2018. World atlas of illicit flows. A RHIPTO-INTERPOL-GI assessment. RHIPTO-Norwegian Center for Global Ana lyses, INTERPOL and the Global Initiative Against Transnational Organized crime, Lyon. https://www.interpol.int/ar/content/download/14080/file/World%20Atlas%20of%20Illicit%20Flows-1.pdf. Accessed November 4, 2024.
Pandey, S. K., K. H. Kim, C. H. Kang, M. C. Jung, and H. Yoon. 2009. BBQ charcoal as an important source of mercury emission. *J Hazard Mater* 162(1):536–538.
Perdigão, C. R. V., M. M. B. Júnior, T. A. P. Gonçalves, C. de, S. Araujo, F. A. Mori, A. C. M. Barbosa, F., I. B. de Souza, J. P. Motta, and L. E. de L. Melo. 2020. Forestry control in the Brazilian Amazon I: wood and charcoal anatomy of three endangered species. *IAWA J* 41(4):490–509.
Prayogi, A. W., A. R. Cangara, M. N. Badu, A. Baharuddin, and I. D. N. Marifat. 2020. The impacts of Paraguayan charcoal export to European markets upon deforestation of Paraguay's Chaco forest. *IOP C Ser Earth Env* 575(1):012243.
Reumerman, P. J. and B. Frederiks. 2002. Charcoal production with reduced emissions. 12th European Conference on Biomass for Energy, Industry and Climate Protection, Amsterdam. www.cleanfuels.nl/Sitepdfs/Charcoal Production with Reduced Emissions (paper).pdf. Accessed January 22, 2025.
Rocchi, L., R. Campioni, A. Brunori, and E. Mariano. 2023. Environmental certification of woody charcoal: A choice experiments application. *Forest Policy Econ* 154:103042.
Rozum, J. J. 2009. Smoke flavor. *In:* Ingredients in Meat Products. R. Tarté (Ed). Springer, New York. https://doi.org/10.1007/978-0-387-71327-4_10. Accessed January 22, 2025.
Serrano-Medrano, M., T. Arias-Chalico, A. Ghilardi, and O. Masera. 2014. Spatial and temporal projection of fuelwood and charcoal consumption in Mexico. *Energy Sustain Dev* 19:39–46.
Taylor, M. J. 2008. The mesquite economy in the Mexican-American borderlands. *J Lat Amer Geog* 7(1):133–149.
USITC DataWeb. 2024. HTS Number 4402 "Wood charcoal (including shell or nut charcoal), whether or not agglomerated. US International Trade Commission. (n.d.). DataWeb. https://dataweb.usitc.gov. Accessed November 11, 2024.
van Dam, J. 2017. The charcoal transition: greening the charcoal value chain to mitigate climate change and improve local livelihoods. Food and Agriculture Organization of the United Nations, Rome. 178 pp. http://www.fao.org/3/a-i6935e.pdf. Accessed August 6, 2024.
van't Veen H, M. B. Eppinga, T. H. Mwampamba, and M. J. F. dos Santos. 2021. Long term impacts of transitions in charcoal production systems in tropical biomes *Environ Res Lett* 16:034009.
Wheeler, E. 2011 Inside Wood - A web resource for hardwood anatomy. *IAWA J* 32:199–211.
Wiedenhoeft, A. C., J. Simeone, A. Smith, M. Parker-Forney, R. Soares, and A. Fishman. 2019. Fraud and misrepresentation in retail forest products exceeds U.S. forensic wood science capacity. *PLoS ONE* 14(7):e0219917.
Wilkinson, J.M., E. J. Evans, P. E. Bilsborrow, C. Wright, W. O. Hewison, and D. J. Pilbeam. 2007. Yield of willow cultivars at different planting densities in a commercial short rotation coppice in the north of England. *Biomass Bioenerg* 31(7):469–474.
Zahnen, J., P. Hirschberger, V. Haag, and T. Lewandrowski. 2020. Analysis of the EU Charcoal Market. WWF Germany: Berlin.