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# ATLAS OF CHARCOAL-BASED GRILLING FUEL COMPONENTS

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Grilling and smoking of food has a long and rich history, and while the practice of food preparation has remained the same, the culinary techniques, appliances, and the types of fuel used have evolved. Consumers can now choose from a wide selection of grilling appliances and purchase an extensive assortment of grilling fuels as manufacturers constantly create new products to compete for the market.

Despite the popularity of gas grills, charcoal briquettes and lump charcoal are still a popular barbecue fuel. However, studies have demonstrated a range of air pollutants associated with charcoal production and combustion and have documented impurities found in charcoal-based grilling fuels (Huang and others, 2016; Jelonek and others, 2020b; Jiang and others, 2018; Johnson, 2009; Kabir and others, 2010, 2011; Kao and others, 2014; Kuo and others, 2006; Oanh and others, 2002; Olsson and Petersson, 2003; Rahman and Kim, 2012; Ruchirawat and others, 2005; Sun and others 2019; Susaya and others, 2010;

Viegas and others, 2012; Vicente and others 2018; Wu and others, 2015). Although most impurities are recognizable only under the microscope, some of these fuels contain visible contaminants, exhibiting, in some extreme cases, as much as 26% impurities by volume (Jelonek and others, 2020b; Figure 1).

Our recent studies strongly suggest that the properties of raw fuels affect the characteristics of combustion emissions (Jelonek and others, 2020a, 2020b, 2021). Therefore, the assessment of the quality of grilling fuels is of critical importance, as combustion smoke has direct contact with food, impacts human safety, and pollutes the atmosphere. However, despite concerns about the negative effects of grilling emissions, limited charcoal quality standards have been implemented around the world. Only 28 European countries have implemented quality standards, production requirements, and testing methods for charcoal briquettes and lump charcoal

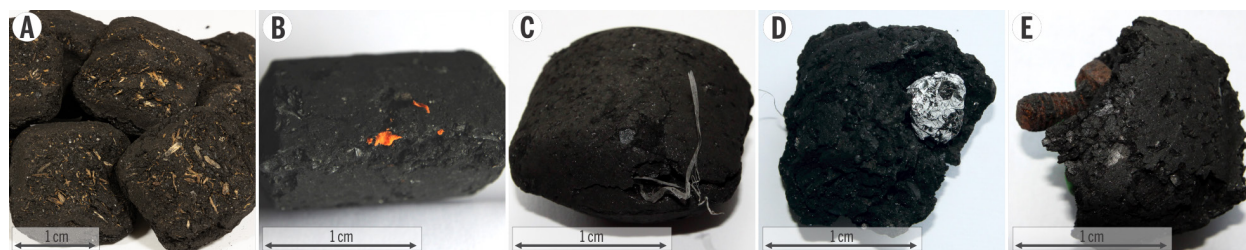


Figure 1. Photographs illustrating megascopic impurities found in charcoal briquettes of this study. A – briquettes with high biomass content (6.1 vol. %), B–C – briquette containing a piece of plastic, D – briquette containing a piece of metal (aluminum foil from candy), E – briquette containing a metal screw. 1 cm = 0.39 inch.

(EN 1860-2, 2005). Even if tests are obligatory, many producers test their products only once to receive a long-term quality certification for the entire product range. In other countries, including the United States, national or state standards do not exist. Some producers claim to test product quality but reports or data are not available to consumers (Jelonek and others, 2020b).

More importantly, a wide range of impurities such as mineral matter, coal, metal, rust, plastics, glues, and synthetic resins documented in previous studies, clearly demonstrate that the current physical and chemical analyses of charcoal-based grilling fuels are not sufficient to guarantee their quality (Jelonek and others, 2020b). One challenge for these methods is assessing the presence of petroleum products such as plastics, rubber, or grease during standard chemical analyses. These pollutants have low ash and moisture content, and they increase the caloric value and mechanical strength of briquettes. Therefore, based solely on basic standard testing, a sample contaminated by petroleum products could be considered an excellent fuel, while in fact their presence lead to the emission of carcinogenic compounds and harmful matter suspended in smoke.

A quick and reliable solution for identifying and quantifying grilling-fuel impurities is reflected light microscopy (Figures 2-3). Reflected light microscopy is a well-known and widely used method in the analysis of coal, source rocks, metals, ceramics, and polymers, and its value was recognized and implemented by the European Committee for Standardization Technical Committee 281 in the European standard (EN 1860-2, 2005) as an obligatory test of inadmissible additions in grilling charcoal-based

fuels. Our team, after analyzing a large number of pellet fuels, defined, described, and documented impurities and modified the existing classification for easier and more precise identification (Drobniak and others, 2021; Jelonek and others, 2020a, 2020b, 2021). The ability to identify and quantify even small contaminants may lead to improvements in fuels quality and modification of testing procedures and existing standards. Most importantly, it will help achieve the production of the highest quality grilling fuels, improve human safety, and lower air pollution (Tables 1-2).

This "Atlas of Charcoal-Based Grilling Fuel Components" features a compilation of over 620 microscopic images taken between 2019 and 2021 using reflected light microscopy. These photomicrographs document the composition of the fuels and demonstrate the array of impurities. As such, this atlas is a valuable source of information for anyone interested in grilling, pellet fuels, optical microscopy, and quality assessments.

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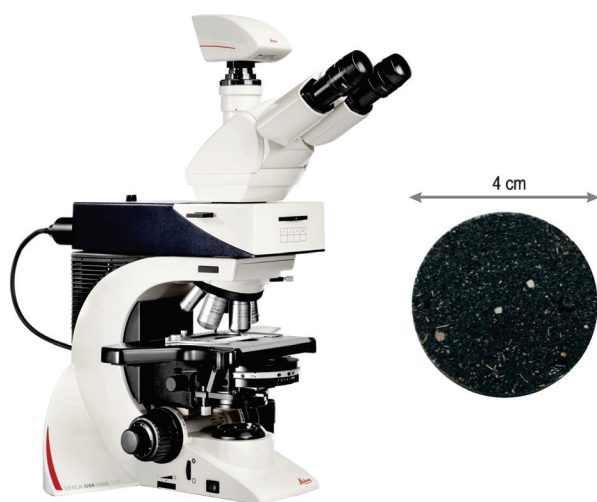


Figure 2. Photograph of the Leica DM 2500P microscope used in this study and a plug used for petrographic analyses.



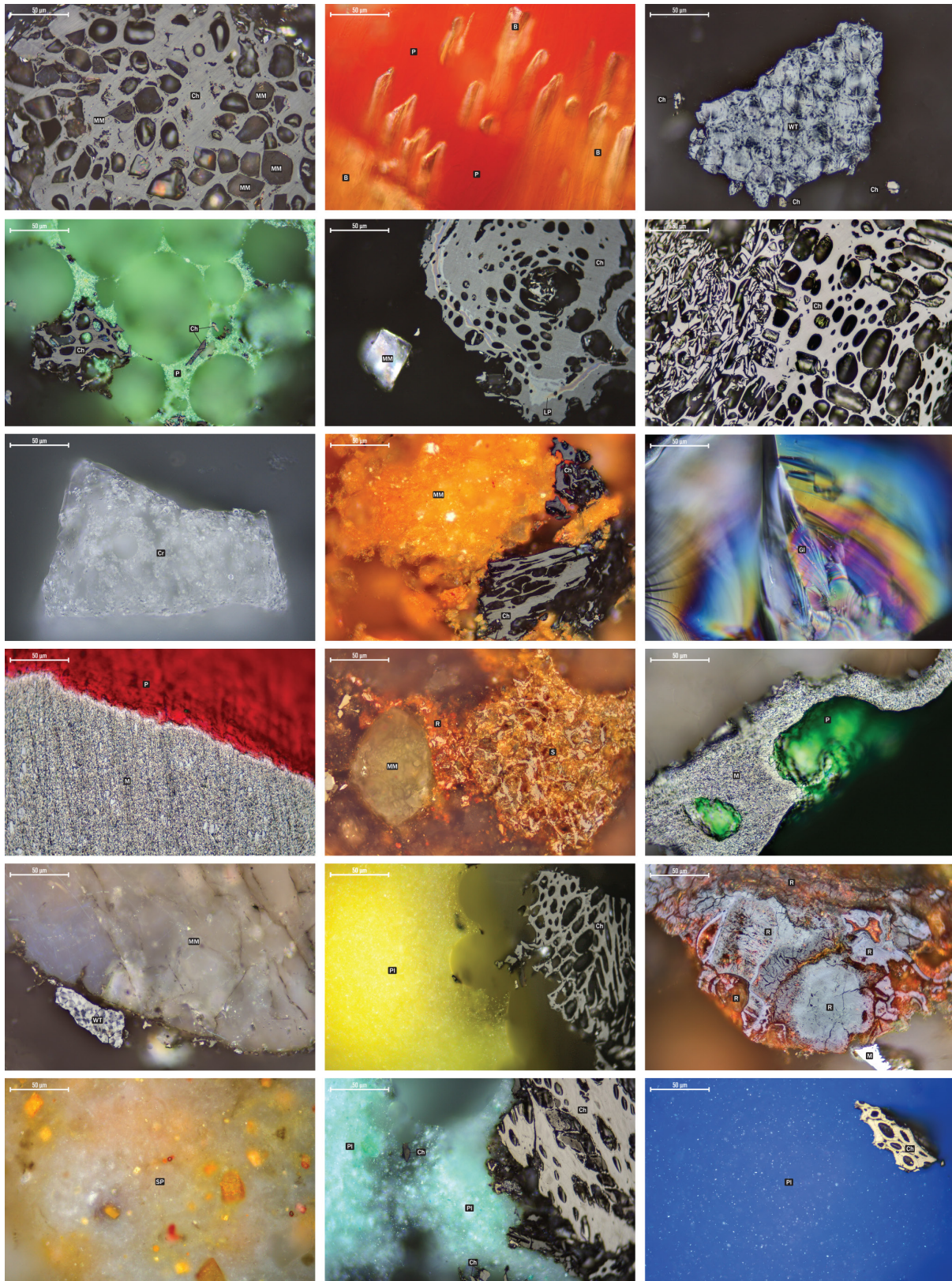


Figure 3. Photomicrographs of selected grilling charcoal-based fuel components in reflected white light and oil immersion. B = biomass, Ch = charcoal, Cr = ceramic, Gl = glass, M = metal, MM = mineral matter, LP = liquid petroleum, P = paint, Pl = plastic, R = rust, S = slag, SP = stone powder, WT = wood tar.

Table 1. Petrographic classification of charcoal briquette and lump charcoal components (modified from Jelonek and others, 2020b).

Charcoal (Ch)		
Biomass (B)		
Bark (Bk)		
Wood tar (WT)		
Coal (C)		
Coke (Co)		
Metal (M)		
Rust (R)		
Paint (P)*		
Mineral matter (MM)	Thermally unchanged	Sand (Sd) Quartz (Qz) Soil (So) Stone powder (SP)
	Thermally / Technologically changed	Ceramic (Cr) Glass (Gl) Sand/clay product (SC)
	Ash (A)	
	Slag (S)	
Petroleum product (PP)	Plastic (Pl) Rubber (Rb) Liquid petroleum fuels (LP) Grease (Gr) Glue (Gu) Polymer resin (PR) Tar (T)	
Other (binders and preservatives) (O)		

\*Some paints are petroleum-based.

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Table 2. Major components of charcoal-based grilling fuels, their source, and their influence. Full reference list in Jelonek and others, 2020b.

Charcoal	The main component of charcoal briquettes and lump charcoal. A wide range of air pollutants is associated with charcoal production and combustion. Produces a significant amount of ash and odor, but, more importantly, charcoal grilling smoke can contain substances having cancerogenic and mutagenic activity, like particulate matter, black carbon, heterocyclic amines, polycyclic aromatic hydrocarbons, or carbon monoxide which can lead to an increased risk of chronic bronchitis, emphysema, and respiratory tract cancer.
Biomass	Comes from incomplete manufacturing processes or is intentionally added to influence food flavor. Linked to potentially harmful particulate matter and smog emissions. It can contain glued, painted and chemically processed wood, soil, and sand inclusions from harvesting and transportation, or manufacturing dust.
Bark	Often associated with biomass. Might contain elevated mineral matter content (like soil or sand from transportation) and produce more ash than wood. Linked to potentially harmful particulate matter and smog emissions.
Wood tar	Product of carbonization or destructive distillation of wood. In the past, produced mainly as a water repellent for coating ships, roofs, and ropes. Known also for its microbicidal purposes, as a component of cosmetics (anti-dandruff agent in shampoos), a scent for saunas, and spice for food. However, combustion of wood tar can lead to emission of gases dangerous to human health and the environment.
Coal	Usually introduced secondarily (storage facilities) but sometimes added intentionally to reduce moisture content and increase the calorific value. Increases the formation of ash, slag, and CO, CO <sub>2</sub> , and SO <sub>x</sub> emissions.
Coke	Contributes to higher levels of toxic metals and organic compounds. May contain sulfides, silicates, and carbonates, which, combined with alkaline ash, leads to faster corrosion of a grill.
Mineral matter	Commonly found, mostly as fine silicates and carbonates. Added intentionally to increase and sustain burning temperature or it originates from wood harvesting, handling, mixing, and manufacturing processes. Does not affect the quality of thermally processed foods, but it increases the weight of the product, and, as a result, consumers pay a higher price for a contaminated product. Can lead to the formation of slag and soot and increases the amount of ash that must be removed after grilling. Makes it more difficult to ignite the fuel, which may prompt the use of flammable substances (harmful to humans and the environment) to make ignition easier.
Metal and rust	Introduced as particles and scraps during the production process. Their presence increases the weight of the product and the amount of ash created upon combustion, and along with other contaminants (e.g., bark and mineral matter), form slag agglomerates.
Petroleum products	Can be added as flammable substances to make ignition easier, but most often come either from the source material (like glue or synthetic resin from old furniture) or were introduced during the manufacturing process (plastics, rubber, and grease). Their presence affects the quality of combustion gases and leads to the emission of carcinogenic compounds and harmful particulate matter suspended in smog.

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