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Determination of element composition in CoffeeBricks before and after incineration

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Abstract

The purpose for this study was to determine the element composition in CoffeeBricks before and after incineration. The difference between element composition in CoffeeBricks (barbecue briquettes made out of spent coffee grounds) and regular barbecue briquettes was also evaluated in this study. Aqua regia digests from the ash residues of CoffeeBricks and the ash residues of regular barbecue briquettes were analyzed with Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES). H_2SO_4/H_2O_2 digests from unburned CoffeeBricks and plain spent coffee grounds were also analyzed with ICP-AES in order to evaluate the concentration for selected elements before and after incineration. The chosen elements evaluated in this study had concentrations higher than 0.1 ppm in the measured samples according to the ICP-AES analyses. Element concentrations are presented as mg trace element/g ashes or mg trace element/g sample.

The ash residues of regular barbecue briquettes contained higher concentration of Al, Ca, Fe, Mg and S. The ash residues of CoffeeBricks contained higher concentration of B, Cu, Fe, K, Mn, Na and P. One-way ANOVA showed that there were differences in concentration for the elements Ca, K, P, Na and S between the ash residues of the two different types of CoffeeBricks and regular barbecue briquettes for α=0.001. One-way ANOVA also showed differences in concentration for the elements Ca, K, P and Na between the two different types of unburned CoffeeBricks and plain spent coffee grounds for α=0.01.

Contents

Abbreviations

ANOVA .... Analysis of Variances

B .... Ash residues from regular barbecue briquettes

CCD .... Charge-Coupled Device

CG .... Spent coffee grounds

C1 .... Ash residues from CoffeeBricks, prototype 1

C2 .... Ash residues from CoffeeBricks, prototype 2

C3 .... Ash residues from CoffeeBricks, prototype 3

ICP-AES .... Inductively Coupled Plasma Atomic Emission Spectroscopy

ICP-MS .... Inductively Coupled Plasma Mass Spectrometry

UC2 .... Unburned CoffeeBricks, prototype 2

UC3 .... Unburned CoffeeBricks, prototype 3

%RSD .... Relative Standard Deviation (as percentage)

Introduction

Barbecuing, as a way of cooking food, is very favored in the whole world. Data from 2006 shows that the British population alone barbecue 60 million times a year [1]. Since the briquettes used today usually consists of charcoal products such as wood or leafy trees [2], a barbecuing session has an environmental footprint equivalent to driving an European passenger car for 35 km[1], considering only the volatile emissions. Recent studies have also suggested that the ashes derived from regular barbecue briquettes contains elements e.g As, Cd, Cu, Mn and Pb that may be harmful for the environment and the human health [3].

As one of the worlds most popular beverages, coffee produces tons of spent coffee grounds each year only by human drinking consumptions [4]. The company *ThreeSixty* has found a way of using these residues for barbecuing food. By combining recycled coffee grounds, sawdust and molasses *ThreeSixty* has produced CoffeeBricks which is an alternative to barbecue briquettes and introduces a new opportunity for a more ecological way of barbecuing.

The aim of this study was to examine whether or not CoffeeBricks are more environmental and human friendly than regular charcoal briquettes mainly used today for barbecuing food. The mineral and element composition in CoffeeBricks and regular briquettes were determined by Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES) analyses. Plain spent coffee grounds were also analyzed in order to determine which elements that derives from the spent coffee grounds in the CoffeeBricks. The element composition in CoffeeBricks before and after incineration was also evaluated by analyzing unburned CoffeeBricks with ICP-AES. Two different sample preparation methods were used in order to digest the samples before the analysis.

The significant differences between element concentrations in the different samples were evaluated with an one-way Analysis of Variances (ANOVA).

Theory and analytical principles

3.1 Inductively Coupled Plasma Atomic Emission Spectroscopy

Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES) is an analytical method used for detecting inorganic materials, often trace metals in different compounds or matters. ICP-AES is an optical multi-element emission technique with inductively coupled plasma. A spark from a Tesla coil ionizes the pure argon gas and ions and free electrons are accelerated by a radio frequency field. A temperature of 6000°C to 10000°C can be maintained through the entire gas and the energy transferred from collisions between the electrons and the atoms sustain the plasma. A little volume of the sample solution is injected to the nebulizer which creates a fine aerosol of the sample solution. The plasma atomizes the dry aerosol of analyte and the emission for different elements are divided into separate wavelengths. A spectrum of wavelengths can be chosen which makes it possible to quantitatively determine a range of elements simultaneously [5]. An image of how ICP-AES works is shown in figure 3.1.

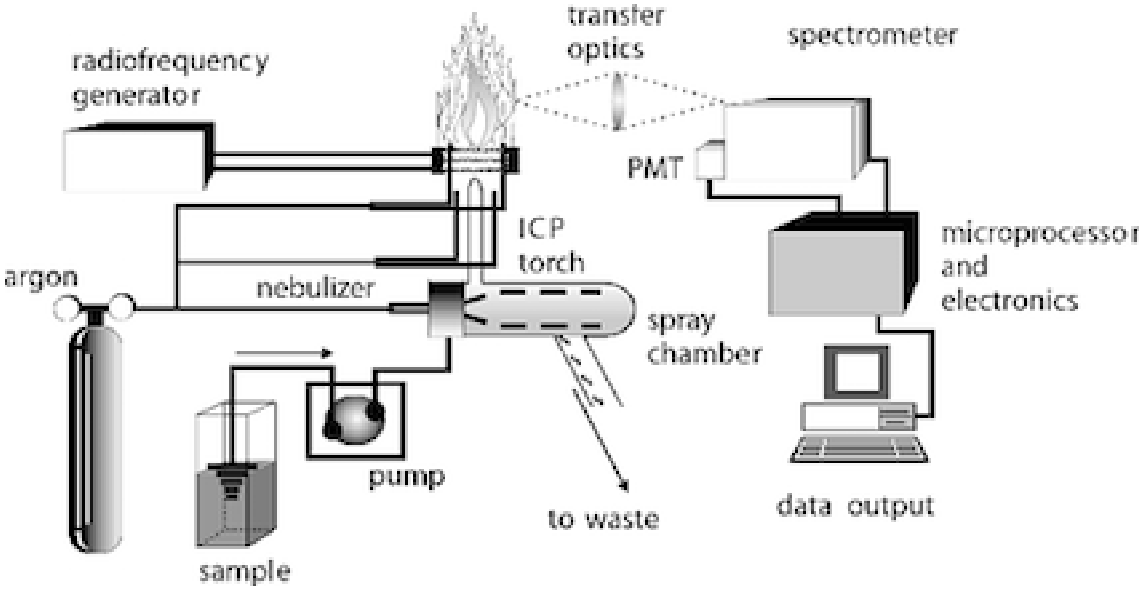

Figure 3.1: A schematic picture of how ICP-AES operates [6].

3.2 Sample dissolving for analyses

There are different ways of digesting inorganic analytes from an organic matrix [5]. A recent study has shown that digestion with concentrated HNO_3 and concentrated H_2O_2 in closed vessels using a microwave system, is a great way of digesting trace elements in spent coffee grounds [7]. Another study has shown that digestion with concentrated HNO_3, H_2O_2 and HF (in a 3:1:0.5 mixture) in a pressure bomb can also be used to digest trace metals in spent coffee grounds [8]. However, the different matrixes in those studies were just plain spent coffee grounds. The CoffeeBricks analyzed in this study also contained sawdust and molasses. A study made of Sharp et. al showed that the ash residues from barbecue briquettes made of charcoal or lump woods, could be digested with an aqua regia solution (three parts HCl and one part HNO_3) in an open system [3].

The method chosen for dissolving the samples were the one Sharp et al. used. The aqua regia wet digestion were chosen since the element composition in regular barbecue briquettes were also to be analyzed. The CoffeeBricks also contained a high amount of sawdust and not just only plain spent coffee grounds. The lack of an available microwave digestion system in the lab, was also considered when choosing the digestion method.

Although aqua regia is a strong oxidizing agent, the organic compounds in unburned CoffeeBricks and plain spent coffee grounds, were not completely dissolved. The unburned CoffeeBricks and the spent coffee grounds were therefore digested with concentrated H_2SO_4 and H_2O_2, since the mixture of those two acids in high temperatures rapidly dissolves organic materials.

Materials and Methods

4.1 Instrumentation

Throughout the whole experiment a Spectro Ciros ICP-AES system (Kleve, Germany) with Smart Analyzer Vision software was used with a cyclonic spray chamber, lichte nebulizer, and Charge-Coupled Device (CCD) detector. The operating conditions are described in table 1.

Table 1: ICP operating conditions

Generator power (W)	1400
Nebulizer	Modified Lichte nebulizer
Spray chamber	Cyclonic
Outer gas (L/min)	14
Intermediate gas (L/min)	0.9
Nebulizer gas (L/min)	0.9
Nebulizer pressure (bar)	3.2
Sample uptake (mL/min)	2

Throughout the whole experiment all the samples were weighed with a Mettler Toledo AE240. The furnace used for ashing the CoffeeBricks was a Carbolite furnace.

4.2 Chemicals and materials

Prior to all experiments, all equipment used was washed with concentrated HNO_3 (65%) purchased from Merck (Darmstadt, Germany), pro analysi and rinsed with Milli-Q water. Concentrated HNO_3 (65%) and concentrated HCl (37%) used for the sample digestion were both purchased from Merck (Darmstadt, Germany), pro analysi. Concentrated H_2SO_4 (95-97%) and concentrated H_2O_2 (30%) used for the sample digestion of the unburned products were both purchased from Merck (Darmstadt, Germany), pro analysi. The filtrates were filtered through a 12.5 cm 00H filter paper. Milli-Q water was used throughout the whole experiment.

4.3 Samples and sample processing

Three different kinds of CoffeeBricks (C1,C2 and C3) with different composition were given from the company *ThreeSixty*, for analysis. The first type of CoffeeBricks to be analyzed (C1) had a composition of 50% spent coffee grounds, 40% wheat flour and 10% sugar mixed with water. However, since C1 consisted of wheat flour and the amount of spent coffee grounds in C1 was not as high as the company *ThreeSixty* was aiming for, and therefore not close to the final product, C1 was only used in the experiment prior to determine which kinds of trace elements that were to be measured.

The second type of CoffeeBricks (C2) had a composition of 70% spent coffee grounds, 20% sawdust and 10% molasses and the third type (C3) had a composition of 60% spent coffee grounds, 30% sawdust and 10% molasses. Since the amount of spent coffee grounds in C2 and C3 lies in the range of what *ThreeSixty* requires, the prototypes of C2 and C3 are very close to the final product of CoffeeBricks that *ThreeSixty* will be launching. Therefore, C2 and C3 were the kind of CoffeeBricks to be analyzed quantitatively and qualitatively. Unburned C2 and C3 (UC2/UC3) were also analyzed quantitatively and qualitatively in order to determine element composition in CoffeeBricks before and after incineration.

The regular barbecue briquettes (B) made of 100% leafy trees from the brand ”Bricketter” were purchased from a local store and contains coal, water and binding agents approved for human consumption.

C1, C2 and B were barbecued on 98.6% pure aluminium foil separately with etOH used as a lightning fluid. However, since it was difficult to receive ashes from barbecuing the CoffeeBricks outdoor for the analysis, C2 and C3 were ashed in furnace in 350°C for 2 h and then 550°C for 22 h. The CoffeeBricks and the barbecue briquettes were accurately weighed before and after being ashed/barbecued. The residual ashes from C2, C3 and B were powdered in a fume hood using an agate pestle and mortar and stored in polyethylene bags prior to analyzing. UC2 and UC3 were powdered and stored the same way as the residual ashes.

Spent coffee grounds (CG) from the coffee brand Zoega was dried in oven in 110°C over night prior to analyzing.

4.4 Sample digestion and extraction

Prior to the sample digestion with aqua regia, the micro Kjeldahl-flasks used were washed with $2+2$ mL concentrated HNO_3 (65%) in an aluminium block (150°C) for about an hour. After being rinsed with Milli-Q water the flasks were dried in an oven (130°C) for about 4 hours.

About 500 mg of the residual ashes from the barbecued and furnace-ashed CoffeeBricks and the barbecued regular briquettes were accurately weighed. Two sets of each sample were weighed in. A volume of 8 mL aqua regia was pipetted to each of the micro Kjeldahl-flasks containing the ashes and to an empty one (serving as a blank). The samples were digested in 80°C in an aluminum block for about two hours. Since a small amount of solid material was seen in the flasks, the contents of the volumetric flasks and additional Milli-Q water was filtered. The filtrates were collected in 50 mL falcon tubes prior to ICP-AES analysis and the sample solutions were diluted with Milli-Q water to 50 mL.

Prior to the sample digestion in H_2SO_4/H_2O_2, 50 mL volumetric flasks were washed with concentrated HNO_3 (65%) and then rinsed with Milli-Q water. About 500 mg of CG, UC2 and UC3 were weighed into the 50 mL volumetric flasks. Two sets of each sample were weighed in. A volume of 7 mL of H_2SO_4 (95-97%) was pipetted to each of the volumetric flasks containing the samples and to an empty one (serving as a blank). The flasks were heated on a hot plate in a fume hood for about 10 minutes. Concentrated H_2O_2 (30%) was drop-wise added to the volumetric flasks until all the organic compounds had been digested and only a clear liquid consisted in the volumetric flasks. The cooled contents were diluted up to the mark with Milli-Q water. After being mixed, the contents in the volumetric flasks were filtered and the filtrates were collected in 15 mL falcon tubes prior to ICP-AES analysis.

For quantification of elements with a higher concentration than 5 ppm, 0.1 mL of the already diluted aqua regia digests and the H_2SO_4/H_2O_2 digests were pipetted and diluted with additional Milli-Q water to 10 mL in falcon tubes, i.e diluted 100 times.

4.5 Moisture and ash content

In order to determine the H_2O content, the three different kinds of CoffeeBricks and the regular briquettes were weighed separately on 98.6% pure aluminium foil before and after being in the oven in 110°C for 24 h.

By weighing the CoffeeBricks and the regular barbecue briquettes before and after being barbecued or ashed in furnace, the ash content was determined.

4.6 Elemental analysis

The aqua regia digests from C1 was analyzed with a multielement standard solution (9.7 ppm) containing 29 different elements, in order to preliminary examine which elements CoffeeBricks consists of. Although ICP-AES may detect elements with concentrations as low as 0.01 ppm, the elements selected to be studied were those that had concentrations higher than 0.1 ppm in the measured solutions.

Aqua regia digests and H_2SO_4/H_2O_2 digests were analyzed with ICP-AES. The instrument was calibrated using standard solutions with the different concentrations of 0 ppm, 1 ppm and 5 ppm, each made from a multielement standard solution (9.7 ppm). Depending of which samples that were analyzed, the three standard solutions also contained either a volume of 8 mL aqua regia (for the aqua regia digests) or a volume of 7 mL H_2SO_4 (for the H_2SO_4/H_2O_2 digests) per 50 mL (matrix matched).

The same sample was analyzed on more than one day with at least two different digests each day. %RSD was calculated from the results within one day. The presented concentrations are those with the lowest %RSD for each element.

One-way ANOVA was used for evaluating the differences between the means of the measured concentrations of the elements Ca, K, P, Na and S for the ash residues of C2, C3 and B.
One-way ANOVA was also used for evaluating the differences between the means of the measured concentrations of the elements Ca, K, P and Na between UC2, UC3 and CG.

The same sample of C2 in aqua regia was analyzed three times in order to determine the precision of the instrument.

Results and Discussion

5.1 Precision of the instrument

From the repeated measurements of C2 in the same digests, instrument precision was determined to 1.1%RSD.

5.2 Moisture and ash content in the different samples

The moisture content for the different samples are presented in table 2.

Table 2: Moisture content [%]

C1	6.2
C2	7.9
C3	10.7
B	1.0

The moisture content in CoffeeBricks were much higher than in regular barbecue briquettes. This could be the reason for the difficulty of receiving ashes for analyses when barbecuing the CoffeeBricks outdoor on a barbecue grill. In order to enhance the barbecue experience, the CoffeeBricks should be dried even more before leaving the manufacturer. The H_2O content in CoffeeBricks should be around 1%, as the H_2O content in regular barbecue briquettes.

The ash content for the three different kinds of CoffeeBricks and the regular barbecue briquettes are presented in table 3.

Table 3: Ash content [%]

C1	5.8
C2	28.7
C3	5.9
B	36.4

The ash content in percentage in all three different types of CoffeeBricks were lower than the ash content derived from the regular barbecue briquettes. The prototypes C1 and C3 might have had a lower ash content than C2 due to the higher amount of sawdust or wheat flour. Since the ashes, to some extent, consists of trace elements that may be dangerous to the environment, the company *ThreeSixty* should aim for producing products with the same amount of spent coffee grounds (60%) and sawdust (30%) like the prototype C3.

5.3 Detected trace elements

The elements with a concentration higher than 0.1 ppm in the measured solutions were Al, B, Ca, Cu, Fe, K, Mg, Mn, Na, P and S. The mentioned elements were therefore chosen for further analyses.

When evaluating the element concentration in the different ashes, one should have in mind that not all of the samples digested with aqua regia were dissolved. There was still some solid material left in the flasks that were filtered away. Hence, some part of the elements analyzed might have been filtered away. Some part of the elements might also have evaporated, thus the decrease of element concentration in the ashes of C2 and C3 compared to the unburned CoffeeBricks UC2 and UC3.
An increase of element concentration in the ash residues of CoffeeBricks might be due to the mass loss upon ashing the CoffeeBricks in furnace. ~ 5 % of the initial mass remained upon ashing, therefore an increase of element concentration up to 20 times for some elements might be expected in the ashes.
The bar charts presented below for each of the element detected are the concentration [mg/g] of each element in the ashes of C2,C3 and B and the concentration [mg/g] of each element in the samples of CG, UC2 and UC3.

An uncertainty in the concentration of the elements Ca, K, Mg and S could also be present due to the lack of the measured solutions being matrix matched when diluted 100 times.

5.3.1 Aluminium

Although aluminum is not dangerous for human beings, Al in excess could be dangerous to the environment and the underwater animal life [9]. The ash residues from regular barbecue briquette (B) contained a higher concentration of Al than the ash residues from CoffeeBricks (C2 and C3), the higher amount of Al in B could be due to the fact that B was barbecued on aluminum foil.
As figure 5.1 demonstrates, the concentration of Al in unburned CoffeeBricks and in spent coffee grounds were higher than in the ash residues of CoffeeBricks. A recent study suggested that Al in barbecue briquettes does not have a high volatility [3], therefore one could infer that the barbecue smoke from CoffeeBricks does not contain a high concentration of Al. One reason for a higher Al concentration in UC2, UC3 and CG could be due to the different sample preparations since there were solid material left in the aqua regia solutions that were filtered away, as mentioned above.

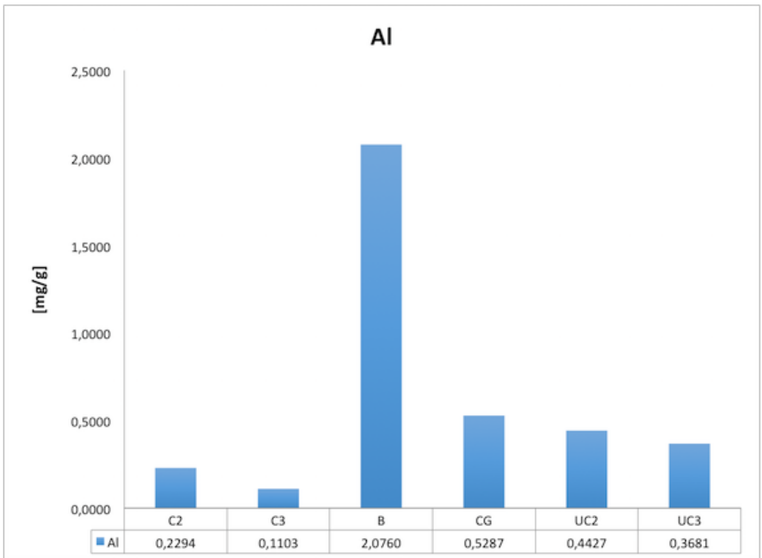

Figure 5.1: Concentration of Al in C2, C3, B, CG, UC2 and UC3.

5.3.2 Boron

According to the ICP-AES analysis, the boron concentration was higher in the unburned CoffeeBricks and in the spent coffee grounds than in the ash residues of CoffeeBricks and regular barbecue briquettes. A reason for this could either be due to the different sample preparations or the volatility of boron. The concentration of boron in the ash residues of regular barbecue briquettes was slightly higher than in the ash residues of CoffeeBricks. Human exposure to boron in low concentrations are not dangerous and human digestion of the element is rather common since boron is an essential element for plant growth [10]. As seen in figure 5.2 the overall concentration of boron in the different samples were rather low (highest concentration was = 0.5352 mg/g) and therefore not dangerous to neither human beings nor the environment.

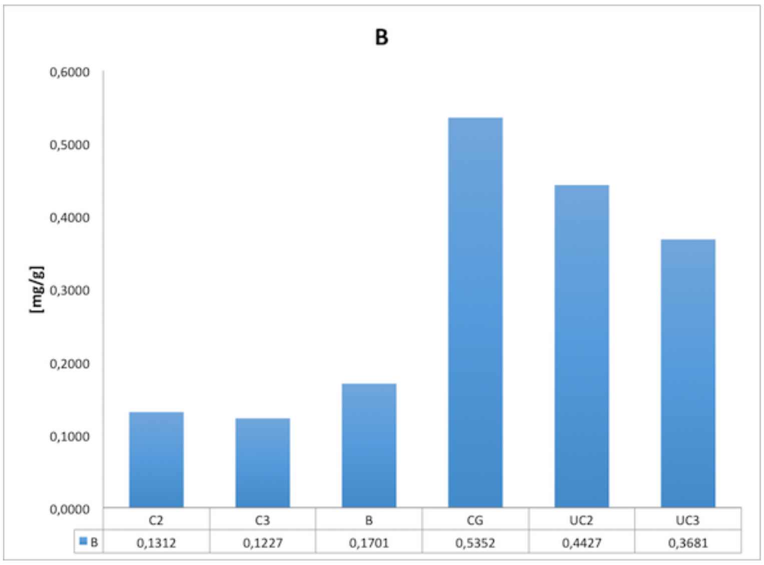

Figure 5.2: Concentration of B in C2, C3, B, CG, UC2 and UC3.

5.3.3 Calcium

Figure 5.3 shows that the ash residues of CoffeeBricks contained much higher concentrations of Ca than the unburned CoffeeBricks. The spent coffee grounds had a lower Ca concentration than all of the other samples. The sawdust in CoffeeBricks and the leafy trees in regular barbecue briquettes might contain a higher concentration of Ca than just plain coffee, thus a lower concentration in spent coffee grounds. The increase of Ca concentration of the ash residues of CoffeeBricks might be due to the mass decrease of CoffeeBricks when being ashed.
A rather high amount of the earth crust consists of Ca (3,6%) and since Ca is an essential element for human beings and animals [10], the high concentrations of Ca in the ash residues of CoffeeBricks and the ash residues of regular barbecue briquettes are not dangerously alarming.

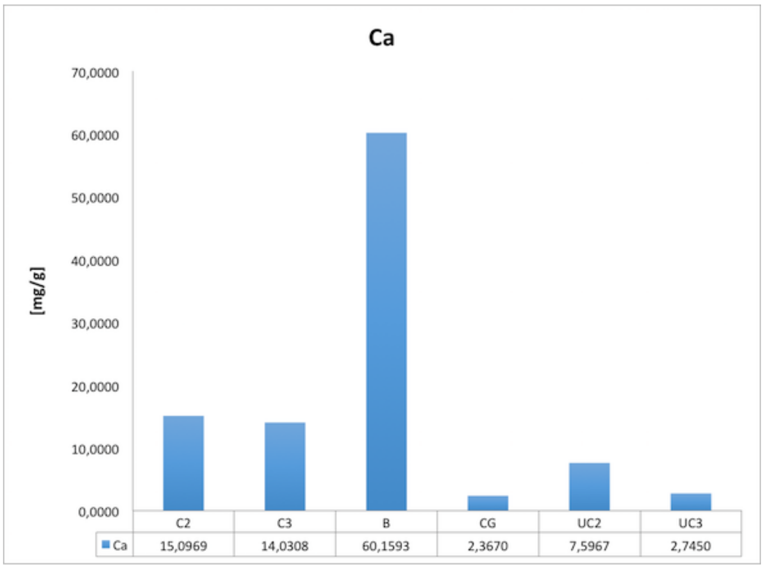

Figure 5.3: Concentration of Ca in C2, C3, B, CG, UC2 and UC3.

5.3.4 Copper

Although copper is an essential trace metal for animals and human beings, very large concentrations of Cu may be toxic to plants [10]. As shown in figure 5.4 the concentration of Cu was higher in UC2 than in UC3. The amount of Cu in CG was also rather high, comparing to the other samples. The higher amount of spent coffee grounds in UC2 might be the reason for a higher Cu concentration in UC2 than in UC3. Since the amount of copper in the samples were low, barbecuing CoffeeBricks or regular barbecue briquettes poses no hazard to the plants.

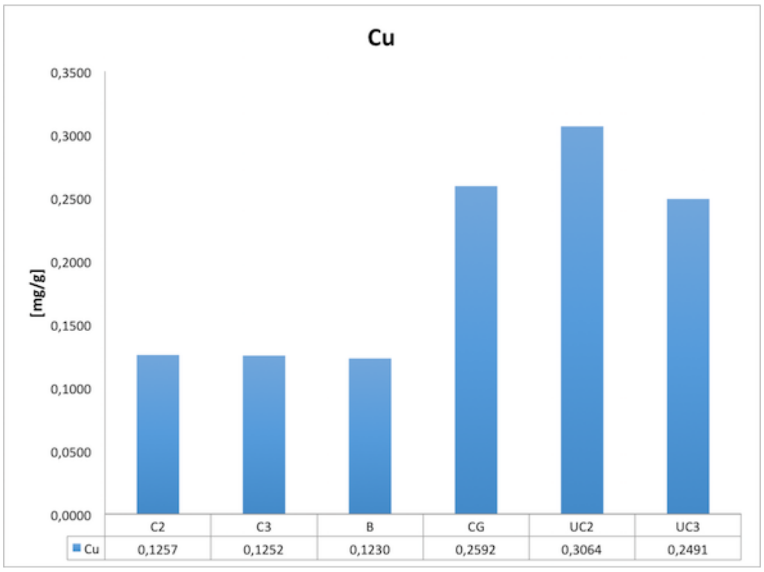

Figure 5.4: Concentration of Cu in C2, C3, B, CG, UC2 and UC3.

5.3.5 Iron

Iron is an essential nutrient for humans, but may in really high concentrations be toxic, especially to small children [11]. Fe in high concentrations could also be dangerous to the environment [9]. Figure 5.5 shows that the ash residues from regular barbecue briquettes contained a higher concentration of Fe than any of the other samples. The ash residues of CoffeeBricks also contained higher concentration of Fe than the unburned ones. The increase of Fe concentration upon ashing may reflect the mass decrease of CoffeeBricks when being ashed.

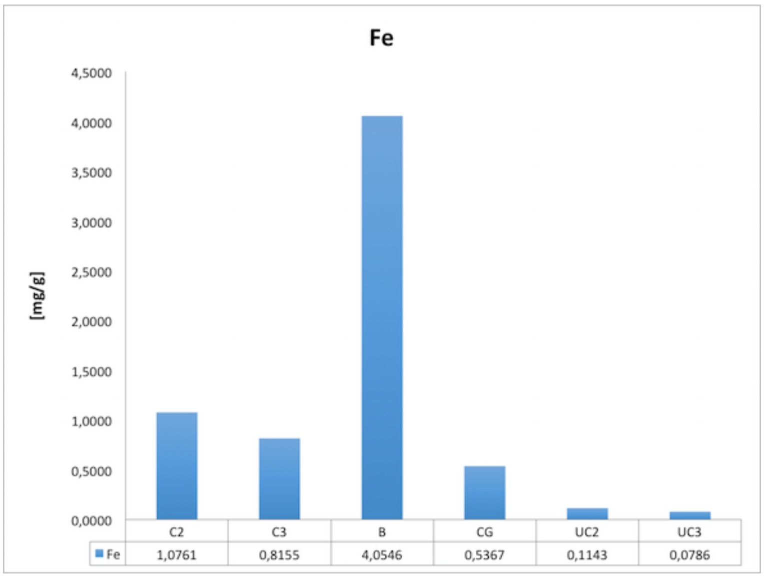

Figure 5.5: Concentration of Fe in C2, C3, B, CG, UC2 and UC3.

5.3.6 Potassium

The ICP-analyses indicated that the amount of potassium increased upon ashing the CoffeeBricks. The ash residues from regular barbecue briquettes contained a much lower concentration of K than the ash residues of CoffeeBricks. A reason for an increase of the K concentration in the ash residues compared to the unburned CoffeeBricks might be due to the percentage loss of CoffeeBricks upon ashing. The different concentrations of K in the samples are shown in figure 5.6. K is one of the main fertilizer for growing plants and is generally not considered as dangerous for humans [10].

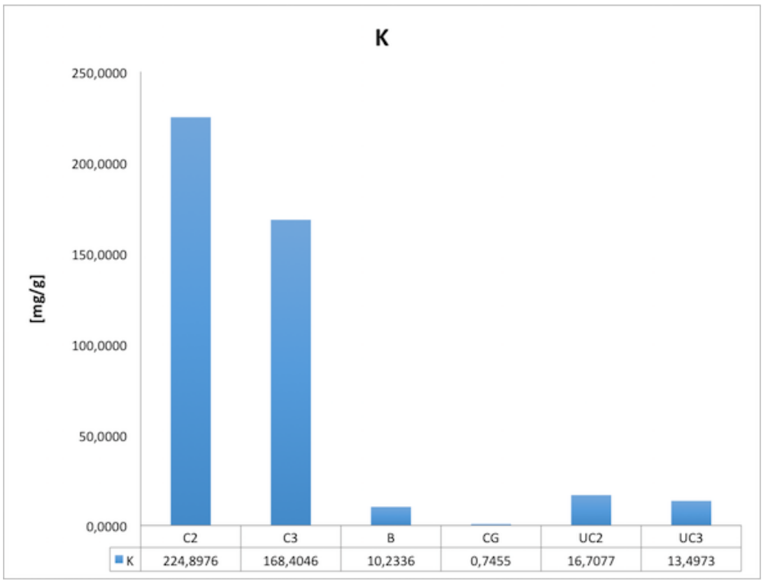

Figure 5.6: Concentration of K in C2, C3, B, CG, UC2 and UC3.

5.3.7 Magnesium

Magnesium is an essential element for humans and animals and is not considered as toxic [12]. As one can see in figure 5.7, the ICP-analyses indicated that spent coffee grounds contained a low concentration of Mg. Ash residues of regular briquettes contained the highest concentration of Mg of all the samples analyzed. Ash residues of CoffeeBricks contained more Mg than the unburned CoffeeBricks, like K, the increase of Mg in the ashes from CoffeeBricks might be due to the loss of mass upon ashing the Coffee-Bricks.

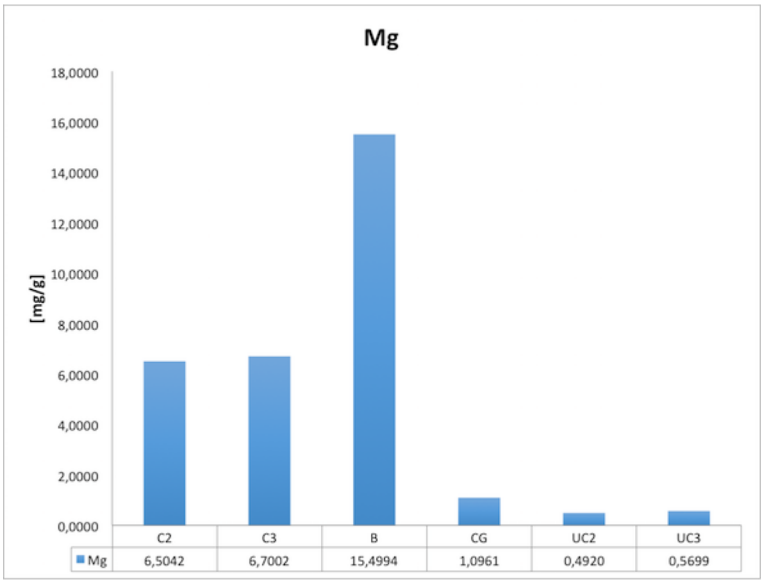

Figure 5.7: Concentration of Mg in C2, C3, B, CG, UC2 and UC3.

5.3.8 Manganese

Human digestion of manganese may in high concentrations have a negative effect on the nervous system. But in everyday life, humans get expose to Mn through the drinking water [13]. The amount of Mn in drinking water may have an effect of the high concentration of Mn in the spent coffee grounds and the CoffeeBricks, since coffee was extracted by drinking water coming from the tap. The analyses indicated a higher concentration of Mn in the ash residues of CoffeeBricks than the ash residues of regular barbecue briquettes. The higher concentration of Mn in UC2 and UC3 than in C2 and C3 might be due to the incomplete dissolution of the samples in the aqua regia solution. However, as figure 5.8 demonstrates, the amount of Mn detected is rather low and opposes no threat for human beings.

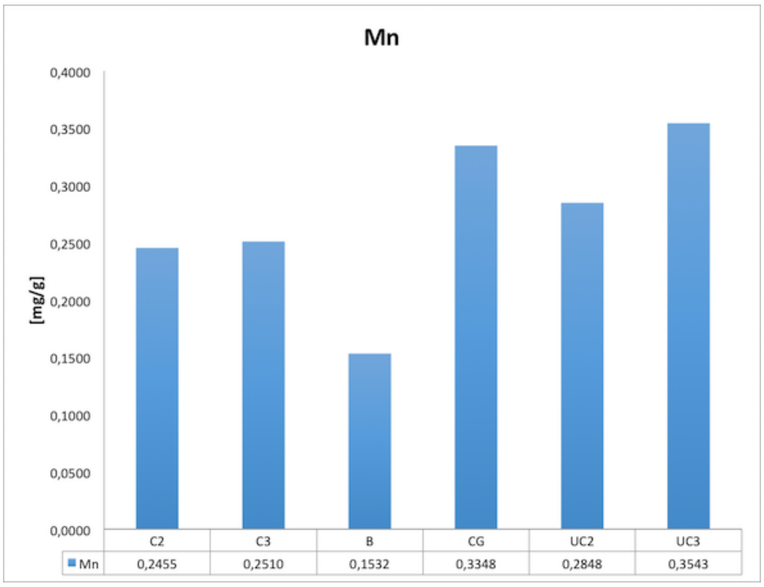

Figure 5.8: Concentration of Mn in C2, C3, B, CG, UC2 and UC3.

5.3.9 Phosphorus

Figure 5.9 shows that the concentration of phosphorus increased upon ashing the CoffeeBricks. The higher amount of sawdust in C3 and UC3 may have an influence of the higher concentration of P than in C2 and UC2. The concentration of P in the ash residues of the regular barbecue briquettes was not as high as in the ash residues of CoffeeBricks. Since P is an essential element for human beings [14] the concentration of P in the ash residues of CoffeeBricks is not harmful for humans.

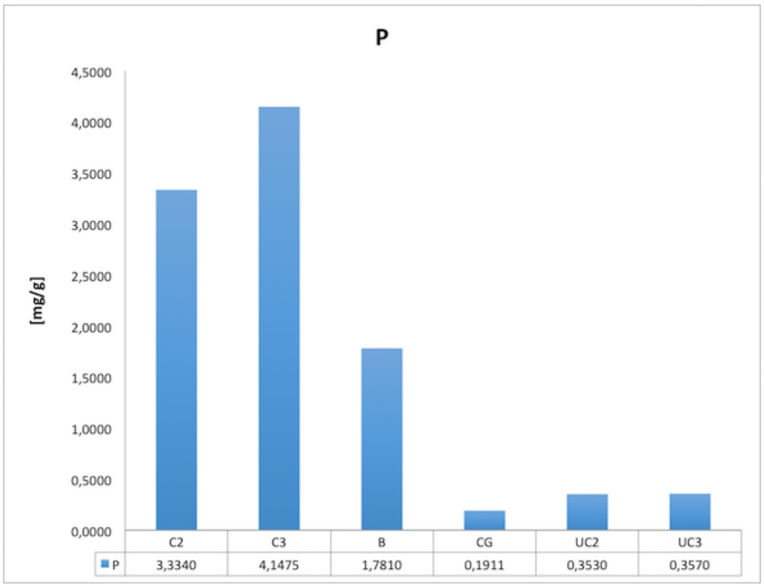

Figure 5.9: Concentration of P in C2, C3, B, CG, UC2 and UC3.

5.3.10 Sodium

As one can see in figure 5.10, the ash residues of CoffeeBricks contained a much higher concentration of sodium than the rest of the samples. The increase of Na in the ashed composites of CoffeeBricks were probably due to the loss of mass upon ashing the CoffeeBricks.
Na is abundant in nature [10] and an essential element for humans [15]. The high concentration of Na in the ash residues of CoffeeBricks is therefore not dangerous to neither humans nor the environment.

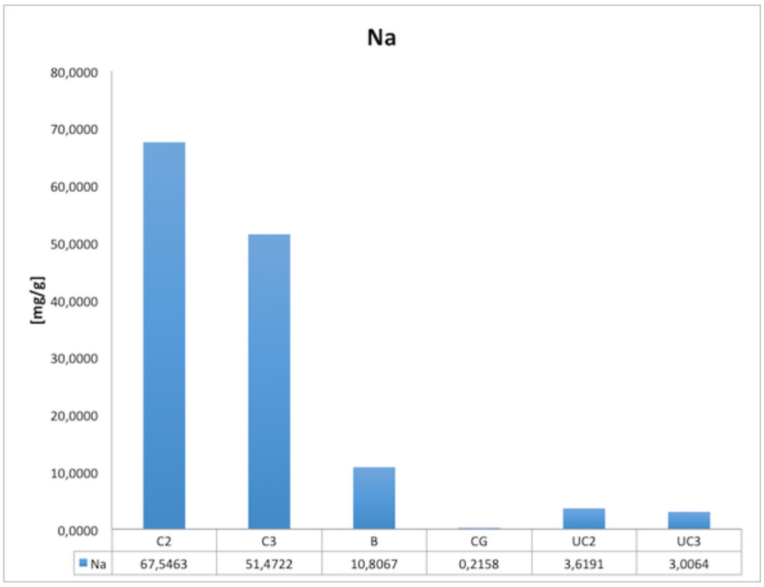

Figure 5.10: Concentration of Na in C2, C3, B, CG, UC2 and UC3.

5.3.11 Sulfur

The analyses of unburned CoffeeBricks (UC2 and UC3) and the spent coffee grounds (CG) were not evaluated for the concentration of S, since H_2SO_4 was used for the digestion, thus increasing the concentration of S in the samples. As figure 5.11 demonstrates, the concentration of S in the ash residues of regular briquettes were higher than the concentration of S in the ash residues of CoffeeBricks. Although S in its pure form is not hazardous to the environment, when burned it reacts with the oxygen in the atmosphere, producing sulfur dioxide which is a gaseous pollutant [9].

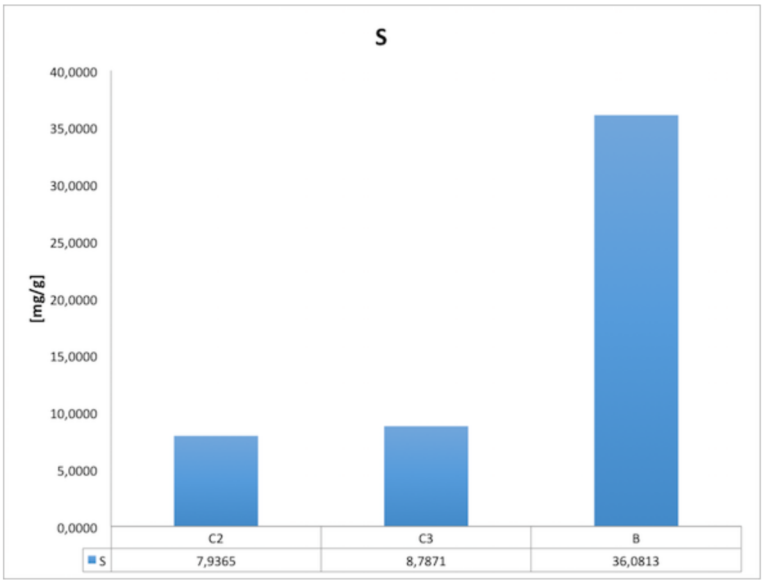

Figure 5.11: Concentration of S in C2, C3, B, CG, UC2 and UC3.

5.3.12 Arsenic, Cadmium and Lead

Since arsenic, cadmium and lead are toxic to human beings and the environment [10], the concentration of As, Cd and Pb in CoffeeBricks and regular barbecue briquettes were evaluated. The ICP-AES analyses showed the concentrations of As, Cd and Pb to be very low (negative readings) in the different samples. Therefore, one might infer that neither the CoffeeBricks nor the regular barbecue briquettes contained high concentrations of the toxic elements As, Cd or Pb.

5.4 Analysis of Variance

One-way ANOVA were made for different elements with high concentration in the ash residues of C2, C3 and B. One-way ANOVA indicated that there was a significant difference at the 99.9% confidence interval ($p<0.001$) between C2, C3 and B for the concentrations of the elements Ca, K, P, Na and S.
One-way ANOVA were also made for the concentrations of the elements Ca, K, P and Na in spent coffee grounds and the unburned CoffeeBricks. One-way ANOVA indicated that there was a significant difference at the 99% confidence interval ($p<0.01$) between the different concentrations of the elements in the spent coffee grounds and the unburned CoffeeBricks.

Conclusion and future aspects

According to this study there is a significant difference in element composition between CoffeeBricks and regular barbecue briquettes. According to the analyses of the residual ashes of CoffeeBricks and the residual ashes of the regular barbecue briquette, neither of the products tested in this study opposes a dangerous threat to human beings nor the environmental, because of the low concentrations of toxic elements detected. Just by looking at the different element composition in CoffeeBricks and in regular barbecue briquettes, one can not say that CoffeeBricks are more friendly to the environment or the human health.
However, one might argue that the recycled spent coffee grounds in CoffeeBricks makes the CoffeeBricks more environmental friendly than barbecue briquettes used mainly today.

In order for a better estimation of the quantitatively differences in element composition in CoffeeBricks before and after incineration, the same sample preparation method should be used for the ash residues and the unburned CoffeeBricks. Further analyses could also be made on unburned regular barbecue briquettes in order to determine element composition in regular barbecue briquettes before and after incineration.
Another approach for determining the element concentrations in the samples should also be tested. The samples could be digested with concentrated HNO_3 and concentrated H_2O_2 in a closed microwave system, in order to evaluate differences in element concentrations without the volatility of the elements being a factor that might influence on the results.
Inductively Coupled Plasma Mass Spectrometry (ICP-MS) could also be used for detecting elements of interests with concentrations as low as 1 ppq (parts per quadrillion) e.g As, Cd and Pb.

For improving the product, CoffeeBricks could be more homogenized before being pressed together, in order to enhance the power derived from the CoffeeBricks. The company *ThreeSixty* might also want to invest in a hydraulic piston press with higher effect than the one used today, since the CoffeeBricks are quite porous.
As mentioned above it is also of great importance to dry the CoffeeBricks further after being pressed together, in order to receive a more easily ignitable product.

Although the CoffeeBricks used in this study was not easy to ignite outdoors on a barbecue grill, in the future, CoffeeBricks might have a chance to compete with barbecue briquettes made out of charcoal and leafy trees used mainly today, after some product improvements from the company.

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