Properties of Charcoal Produced from some Endemic and Exotic Acacia Species Grown in Riyadh, Saudi Arabia

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ABSTRACT

Production and properties of charcoal from four years old *Acacia assak, A. negrii, A. seyal, A. karroo, A. ampliceps, A. stenophylla* and *A. salicina* grown in the Experiments and Research Station, College of Agriculture, King Saud University, Riyadh, Saudi Arabia were studied. The first three species are indigenous while the others are exotic. In February 2001, 21 trees were felled and disks of 20 cm from their stem were cut and shipped to the Wood Testing Laboratory at the Faculty of Agriculture, Alexandria University, Egypt. Specific gravity, charcoal yield and gross heat of combustion of the wood of these species were determined. Wood samples were charcoaled then the physical (apparent density, moisture, gross heat of combustion) and chemical properties (volatile, ash and fixed carbon content) of the charcoal produced were determined. *A. amplecips, A. negrii* and *A. asak* showed high-quality charcoal in terms of high gross heat of combustion and fixed carbon content with low moisture and ash content as compared with the other acacia species under investigation.

Keywords: charcoaling, *Acacia,* Charcoal properties.

INTRODUCTION

Consumption of firewood and charcoal is very large in Saudi Arabia. People traditionally use wood and charcoal for heating in winter and cooking on special occasions. This is still the custom in spite of the availability of electricity, butane gas and other petroleum derivatives at token prices. Felling living trees for the above purposes has caused shrinkage of acreage covered by natural trees and shrubs. To regulate or restrict this process, Ministry of Agriculture introduced a licensing system for utilization of dry (dead) plants for obtaining firewood, for producing charcoal, or for transporting either. The impact of these new regulations is evident, as a result of public awareness campaigns on the importance of maintaining trees and shrubs, as well as applying penalties for violators. There are still unlicensed operations of felling and transporting trees and shrubs. However, the production figures of firewood and charcoal in Saudi Arabia is still far from filling even a part of the large consumption. Therefore, maintaining the existed trees may not enough to fill the gab between supply and real need but adding new tree plantations through afforestation and reforestation enterprises is more realistic providing suitability of planted species to firewood and charcoal production. Acacia trees seem to be the best candidate species for this task. In Saudi Arabia the acacia communities represent the climax stage of xerophytic vegetation and generally have high species cover and low species diversity (Shaltout and Mady, 1996). Because Saudi Arabia is a large country with high diversity in topography and ecosystems it consequently has different plant species including acacias in different regions. Due to the accumulative local experience of the, only few acacia species are used for firewood and charcoal production while others are important sources of browse, pole timber, gum, tannins and other purposes.

The present study was designated to compare the potential of charcoal production and its properties from *Acacia karroo, A. ampliceps, A. stenophylla* and *A. salicina* as exotic species in addition to *Acacia assak, A. negrii* and *A. seyal* as endemic species.

MATERIAL AND METHODS

In order to produce charcoal from acacia and evaluate its properties, woody samples were taken in February 2001 from four years-old trees planted in the field in Riyadh, Saudi Arabia. Planting method and silvicultural practices were presented in details by Aref *et al.* (2003). The studied acacia species were *Acacia assak* (Forssk.), *A. negrii* Pichi-Sermoli, *A. seyal* Del. *A. karroo* Hayne, *A. ampliceps* Maslin, *A. stenophylla* and *A. salicina* Lindley. The first three species are indigenous while the others are exotic. Seeds of both *A. assak* and *A. negrii* were brought from the south west region of Saudi Arabia, while those of *A. seyal* were collected from Riyadh. The seeds of the exotic species were imported from Alexandria, Egypt.

Sampling design

21 trees were randomly chosen from three replicates for studying charcoal production and its properties. These trees representing the seven acacia species; three trees from each species. The trees were felled and a disk of 20 cm height was taken from the base of the stem of each tree. Every disk was sawn into strips of 2.5 cm width. The strips were sawn into cubs of 2.5 × 2.5 × 2.5 cm.

Gross heat of combustion of acacia woods

The processes of converting wood to charcoal and determining the properties of wood and charcoal were carried out in the Wood Testing Laboratory at the Faculty of Agriculture, Alexandria University, Alexandria, Egypt.

Six wood specimens of 2.5 × 2.5 × 2.5 cm from each species were used to determine gross heat of combustion of acacia woods. An adiabatic oxygen bomb calorimeter (Parr 1314 and Parr1108 oxygen bomb) was used following the procedure recommended by the Parr instruction manual and in accordance with ASTM D-2015-77 (1981). The samples were milled and 0.8 g of each was pressed into pellets then placed in a capsule and combusted in the oxygen bomb. The heat produced after combustion of the sample was recorded and converted into calories per gram.

Carbonization process

60 wood specimens of 2.5 × 2.5 × 2.5 cm; nine from each species; except *A. stenophylla* which has only six specimen were oven-dried at 103±2 °C. The specimens were carbonized through an electric tube furnace (Carbolite furnace, model: MTF 12/388). The carbonization process was conducted under inert atmosphere (nitrogen flow gas at rate of 300 ml min^{-1}) and at 450 °C maximum final temperature. The produced charcoal specimens after carbonization were oven-dried at 103±2 °C then weighed. The charcoal yield as a proportion of wood for each wood specimen was calculated using the following equation:

$$\text{Charcoal yield} = (Wc / Ww) \times 100$$

Where, Wc = oven-dry weight of charcoal specimen and Ww = oven-dry weight of wood specimen.

Charcoal properties

1. Physical properties

1-1. Apparent density

The charcoal specimens were aspirated under vacuum until water-logged. The oven-dry weight of ach specimen was measured and the maximum moisture content was calculated. Specific gravity of each specimen was calculated according to the following equation developed by Smith (1954):

$$\text{Specific gravity} = 1/(M_{max} + 1/G_S)$$

Where: M_{max} = Maximum moisture content in grams of water per gram of oven-dry wood, and G_S = specific gravity of wood substance (=1.53).

1-2. Gross heat of combustion

Gross heat of combustion of charcoal specimens was determined using the same procedure that was carried out for wood specimens but without grinding.

2. Chemical properties

Moisture content, volatile matter, ash content and fixed carbon

Moisture content, volatile matter and ash content were determined using the proximate chemical analysis of wood charcoal according to ASTM D-1762-84 (1989), while fixed carbon content was calculated following the equation of Anon (1987).

Moisture content of oven-dried ground charcoal specimen was calculated as a proportion of its initial weight. The same specimen was used for volatile matter and ash content determination.

Volatile matter was extracted by pre-heating the specimen in a tube furnace for two minutes at 300 °C then heating for three minutes at 500 °C and for six minutes at 950 °C. Volatile matter content was calculated as a proportion of the oven-dry weight of the charcoal specimen.

Ash content was determined by heating the charcoal specimen in uncovered crucible at 750 °C for six hours. Ash content was calculated as a proportion of the oven-dry weight of the residue to the oven-dry weight of charcoal specimen.

Fixed carbon content in charcoal specimen was calculated as the difference between 100 and the sum of moisture content, volatile matter and ash content according to Anon. (1987). The carbon content is usually estimated as a "difference", that is to say, all the other constituents are deducted from 100 as percentages and the remainder is assumed to be the per cent of "pure" or "fixed" carbon (FAO 1985).

The data were subjected to statistical analysis of variance as outlined by Steel and Torrie (1980).

RESULTS

Analysis of variance procedure for the data showed significant variation in charcoal yield (P>0.0001) and gross heat of combustion (P>0.0001) between the wood of acacia species. The wood of *Acacia asak* had the highest charcoal yield among all the species followed by the wood of *A. karroo*, *A. stenophylla*, *A. seyal* and *A. salicina* which produced similar yields while both *A. negrii* and *A. amplecips* had almost similar and the lowest yield (Table 1).

On the other hand, gross heat of combustion of *A. negrii* wood was higher than those of the wood of all the other species apart from the wood of *A. salicina*. This as well as *A. seyal* and *A. stenophylla* had close values but were significantly greater than that of *A. karroo* while both *A. amplecips* and *A. asak* had similar and the lowest value for gross heat of combustion (Table 1).

Charcoal properties

The charcoal of acacia species had apparent densities ranged between 0.292 g cm^{-3} (*A. stenophylla*) and 0.467 g cm^{-3} (*A. amplecips*) (P<0.0001). The apparent densities of the charcoal produced from *A. asak*, *A. salicina* and *A. karroo* were 0.356, 0.353 and 0.337 g cm^{-3}, while those of *A. negrii* and *A. seyal* were 0.326 and 0.325 g cm^{-3}, respectively (Table 2).

Chemical properties of charcoal showed significant differences between acacia species. The charcoal produced from *A. amplecips*, *A. asak* and *A.*

karroo had close moisture content proportions comparing with that of *A. stenophylla* which was distinctly the greatest followed by that of *A. negrii* then those of *A. salicina* and *A. seyal*, respectively (P<0.0001) (Table 2).

Table 1. Mean values of specific gravity (g cm^{-3}), charcoal yield (%) and gross heat combustion (cal g^{-1}) of the wood of the seven acacia species

Species	Specific gravity (g cm^{-3})	Charcoal yield (%)	Gross heat of combustion (cal g^{-1})
Acacia amplecips	0.901	*29.77^{d}	4,477^{cd}
Acacia asak	0.687	34.41^{a}	4,474^{cd}
Acacia salicina	0.681	31.01^{bc}	4,615^{ab}
Acacia karroo	0.650	32.09^{b}	4,444^{d}
Acacia negrii	0.629	30.59^{cd}	4,714^{a}
Acacia seyal	0.627	31.16^{bc}	4,579^{bc}
Acacia stenophylla	0.564	31.98^{b}	4,576^{bc}

*Values followed by the same superscript letters in each column are not significantly different at α= 0.05 according to Duncan's multiple range test.

Charcoal produced from different acacia species had ash contents were significantly different (P<0.0001). The wood of *A. negrii* produced charcoal with only 3.22% ash which is far lower than those of the other species followed by that of *A. salicina* (4.53%) then *A. asak* (5.20%) comparing with 5.37, 5.70, 6.42 and 7.02% for *A. amplecips*, *A. stenophylla*, *A. karroo* and *A. seyal*, respectively (Table 2).

Volatile matter in charcoal of acacia species ranged from 27.25% (*A. negrii* and *A. stenophylla*) to 31.56% (*A. asak*). The proportions of volatile matter in the charcoal of other acacia species did not significantly differ (Table 2).

The greatest proportion of fixed carbon in the charcoal produced from acacia species was that of *A. negrii* (62.63%), while the lowest was that of *A. karroo* (56.92%) (Table 2).

Significant differences in the gross heat of combustion were found between the charcoal of acacia species (P<0.0001). The highest value was obtained for the charcoal of *A. amplecips* (7,032 cal g^{-1}) while the charcoal of the other species had similar values but that of *A. seyal* which had the lowest value (6,590 cal g^{-1}) (Table 2).

Table 2. Mean values of apparent density, AD (g cm^{-3}); moisture content, MC (%); ash content, (%) volatile matter, VM (%); fixed carbon, FC (%) and gross heat combustion, GHCC (cal g^{-1}) of charcoal of some acacia species.

Species	AD (g cm^{-3})	MC (%)	Ash (%)	VM (%)	FC (%)	GHCC (cal g^{-1})
Acacia amplecips	*0.467^{a}	5.53^{cd}	5.37^{bc}	28.23^{ab}	60.87^{ab}	7,032^{a}
Acacia asak	0.356^{b}	5.35^{d}	5.20^{bc}	31.56^{a}	57.89^{ab}	6,763^{ab}
Acacia salicina	0.353^{b}	6.24^{bc}	4.53^{cd}	29.22^{ab}	60.02^{ab}	6,838^{ab}
Acacia karroo	0.337^{b}	5.38^{d}	6.42^{ab}	29.11^{ab}	56.92^{b}	6,847^{ab}
Acacia negrii	0.326^{b}	6.81^{ab}	3.22^{d}	27.25^{b}	62.63^{a}	6,865^{ab}
Acacia seyal	0.325^{b}	6.13^{bc}	7.02^{a}	28.08^{ab}	58.76^{ab}	6,590^{b}
Acacia stenophylla	0.292^{c}	7.19^{a}	5.70^{abc}	27.28^{b}	59.83^{ab}	6,746^{ab}

*Values followed by the same superscript letters in each column are not significantly different at α= 0.05 according to Duncan's multiple range test.

The proportion of fixed carbon in the charcoal of the other acacia species did not significantly different.

DISCUSSION

Wood properties of acacia species

Riley and Brokensha (1988) and Hines and Eckman (1993) described the desirable criteria for firewood species as rapid growth, high volume production, dense wood with a low moisture content, relatively easy to cut, easy to handle, slow burning with high calorific value, producing very little smoke without objectionable nor toxic fumes and neither spits nor sparks. These criteria are found in many *Acacia* species and other woody species. The acacia species used in the present study were examined for their potential of charcoal production and gross heat of combustion. The results indicated that the specific gravity of these species ranged from 0.563 to 0.90 g cm^{-3} that more or less close to the desirable criteria for the quality charcoal. FAO (1962) suggested specific gravity of 0.7-0.9 for efficiency and ease manufacture of charcoal. Megahed *et al.* (1998) reported specific gravity of 0.621 and 0.623 g cm^{-3} for the wood of six years old *A. amplecips* and *A. karroo*, respectively. The values of specific gravity of the same two species in the present study were 0.629 and 0.623 g cm^{-3}, respectively. Charcoal yield of the seven acacia species ranged from 29.77 to 34.41%. The importance of charcoal yield is related to the efficiency of converting wood to charcoal. If charcoal yield of a woody species was as low as 15% the conversion of wood to charcoal will be a wasteful process. Although *A. asak* had the highest wood specific gravity and charcoal yield however, it had low biomss production comparing with the other six acacia species (Aref *et al.* 003). This may limit the efficiency of converting the wood of this species to charcoal. The gross heat of combustion of acacia species in the present study ranged from 4,444 to 4,714 cal g^{-1}. The gross heat of combustion determined for *A. amplecips*, *A. stenophylla* and *A. karroo* accounted for 4,477, 4,567 and 4,444 cal g^{-1}, respectively. This figures concurs with those reported for the same species at age six years by Megahed *et al.* (1998).

charcoal properties of acacia species

The quality of charcoal is defined by various mostly inter-related properties that are measured and appraised separately. The physical properties of charcoal include apparent density, gross heat of combustion while chemical properties include moisture content and volatile matter, fixed carbon and ash content.

The investigated acacia species in the present study differed significantly in their physical properties. The charcoal produced from *A. amplecips* wood had apparent density and gross heat of combustion values were the greatest among all acacia species (0.467 g cm^{-3} and 7,032 Cal g^{-1}, respectively) while those of the charcoal of *A. seyal* and *A. stenophylla* were the lowest (0.325 and 0.292 g cm^{-3}) and (6,590 and 6,746 cal g^{-1}), respectively. Megahed *et al.* (1998) studied six tree species included *A. amplecips*, *A. stenophylla* and *A. karroo* and reported apparent density for their produced charcoal were not accorded with those of the present study. This may due the difference in the age of trees in the two studies and/or the environmental conditions and/or as a result of using different maximum final temperatures in carbonization process. However, the values of both apparent density and gross heat of combustion reported her met, at least in part, the criteria suggest by FAO (1962).

Chemical properties of the charcoal also differed significantly between acacia species. The charcoal that had lower moisture content gave often-higher gross heat of combustion. This because high moisture content lowers the calorific or heating value of the charcoal (FAO 1985). This seems true where *A. stenophylla* that had the highest moisture content had lower gross of heat combustion. The values of moisture content of the charcoal produced from different acacia species fall within the criteria desirable by FAO (1985) in which 7% is the higher limit for moisture content.

The volatile matter in charcoal can vary from a high of 40% or more down to 5% or less (FAO 1985). The charcoal of *A. asak* had the highest volatile matter comparing with *A. negrii* which had the lowest while the charcoal of other species were similar. High volatile charcoal is easy to ignite but may burn with a smoky flame while low volatile charcoal is difficult to light and burns very cleanly. However, high volatile charcoal is preferable for some purposes such as barbecue, while other utilizations as chemical purification and metal manufacture need low volatile charcoal.

Acacia negrii produced charcoal with the highest fixed carbon content (62.63%) among the investigated acacia species while *A. karroo* had the lowest value (56.92%). The fixed carbon content of charcoal ranges from a low of about 50% to a high of around 95% (FAO 1985). Thus charcoal consists mainly of carbon. The charcoal produced from both *A. amplecips* and *A. negrii* which had the highest gross heat of combustion values had also higher fixed carbon content. The same relationship was reported previously (*e. g.* Stimely and Blankenhorn 1985 and Megahed *et al.* 1998). The finding of the present study concurs with the results of Megahed *et al.* (1998) for six woody species included *A. amplecips*, A. stenophylla and *A. karroo*. However, The desirable criteria for charcoal presented by FAO (1962) defined the fixed carbon content of finished product as >75 %. Proportion of fixed carbon content can be controlled through maximum temperature and its residence time during the carbonization process (Hindi 1994). Increasing fixed carbon in such way associated always with decreasing charcoal yield.

Ash content of charcoal produced from acacia species varied significantly with higher proportions were found in the charcoal of both *A. seyal* (7.02%) and *A. karroo* (6.42%) and lower proportion for those of both *A. salicina* (4.53%) and *A. negrii* (3.22%).

The ash content of charcoal varies from about 0.5% to more than 5% depending on the species of wood. Good quality lump charcoal typically has an ash content of about 3% (FAO 1985).

CONCLUSION

The results of the present study offered a guide for the potential of producing charcoal from the investigated acacia species which may be beneficial when choosing the species to be planted for firewood or energy production. The process of converting wood to charcoal can be modified to meet the most popular criteria for firewood and charcoal production and ameliorated to suit the large-scale production. *A. amplecips*, *A. negrii* and *A. asak* seems to be the most promising acacia species comparing with the other species tested.

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الملخّص عربي

صفات الفحم المنتج من بعض أنواع الأكاسيًا المتوطنة و المستوردة النامية في الرياض بالمملكة العربيّة السعوديّة

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خصّصت هـذه الدراسـة لمقارنة إنتاج الفحم من أشجار أكاسيا عمرها أربعة سنوات منزرعة في محطة الأبحـاث و الـتجارب الزراعيّة، كليّة الزراعة، جامعة الملك سعود، الرياض، المملكة العربيّة السعوديّة و تقدير صفات هذا الفحم. هذه الأنواع هي: *Acacia asak* و *A. negrii* و *A. seyal* و *A. karroo* و *A. ampliceps* و *A. stenophylla* و *A. salicina* . الأنــواع الثلاثة منها محليّة أمّا الأربعة الأخرى فهي مســتوردة من مصر. في فبراير ٢٠٠١، أسقطت ٢١ شجرة و أخذت أقراص طول كل منها ٢٠ سم من ساق كـل مــنها و أرســلت إلى معمل اختبارات الأخشاب بكليّة الزراعة جامعة الإسكندريّة، مصر. تم تقدير الثقل الــنوعي و إنــتاج الفحم و حرارة الاحتراق الكليّة في عينات من أخشاب هذه الأنواع ثمّ فُحّمت هذه العينات و قــدرت فيها صفات الفحم الطبيعيّة (الكثافة الظاهريّة و حرارة الاحتراق الكليّة) و الصفات الكيميائيّة (المحتوى الــرطوبي و المــواد المــتطايرة و الرماد و الكربون المثبّت). و قد أنتجت الأنواع *A. amplecips, A. negrii and A. asak* نوعيّــة جيدة من الفحم من حيث حرارة الاحتراق الكليّة و محتوى الكربون المثبّت مع محتوى رطوبي و رماد قليل بالمقارنة مع أنواع الأكاسيا الأخرى التي تمت دراستها.