Fuelwood Characteristics of Six Acacia Species Growing Wild in the Southwest of Saudi Arabia as Affected by Geographical Location

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Wood energy is derived from a variety of wood-based sources, the most prominent of which is the fuelwood obtained directly from trees and forests. The genus *Acacia* includes over 1,000 species spread all over the world. Six indigenous acacia species that grow naturally in the southwest region of Saudi Arabia were selected in November 2010 from the Abha and Al-Baha forests to determine the heating values and chemical constituents of their wood on a comparative basis. The results showed that they differed significantly in their chemical components and heating value. The highest heating value (20.45 MJ kg^{-1}) was found in the wood of *A. tortilis*, while *A. ehrenbergiana* had the lowest (18.00 MJ kg^{-1})—although the latter species is the most popular in the Kingdom for firewood. Trees grown in the Al-Baha region had greater heating values than those in the Abha region. The heating values were highly positively correlated with the contents of lignin (R^2=0.70) and total extractives (R^2=0.56).

Keywords: *Fuelwood; Acacia species; Heating value; Forests; Chemical constituents*

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INTRODUCTION

Wood has been the most important fuel used by humans for thousands of years. Because of the harnessing of fossil and nuclear fuels in recent times, the use of wood has declined. However, it is still a major source of energy in both developed and developing countries (Erakhrumen 2009). Fuelwood shortage is being felt at the national and global levels. Numerous tree species need to be evaluated for their potential to overcome this shortage (Geyer *et al*. 2008). Use of woody biomass for obtaining heat energy has increased dramatically over the last few decades (Bilandzija *et al.* 2012).

Like many other developing countries, Saudi Arabia relies heavily on fuelwood as a major energy source for cooking and heating (El-Juhany and Aref 2003); therefore, the consumption of firewood and charcoal is very high. Forests in Saudi Arabia are concentrated in the Sarawat Mountains (2.7 million ha) in the southwestern part of the country, but can also be found in the Hejaz Mountains in the north and the Asir Mountains in the south (El Atta and Aref 2010). The forests of Saudi Arabia could potentially produce over 18 million tons of biomass annually (FAO 2005). In connection with the gathering of commercial firewood, the uprooting of plants and the consequent soil disturbance has caused a significant degradation of rangeland in Saudi Arabia (Al-Rowaily 1999). The consumption of *Acacia tortilis* ("samor" firewood) is much higher than the vegetation cover's capability to meet the escalating demand (Al-Abdulkader *et* *al*. 2004). The efforts undertaken by the Ministry of Agriculture to reclaim forest and rangeland could be met with little or no success (Al-Rowaily 1999 and El-Juhany 2009).

There are 15 indigenous species of *Acacia* widely distributed throughout Saudi Arabia (Chaudhary 1983) that thrive in the arid and semi-arid regions. In Saudi Arabia, the acacia communities represent the climax stage of xerophytic vegetation and generally have a high cover and low species diversity (Shaltout and Mady 1996). Most of these provide wood that is used as fuel and timber and form a good source of gum, tannins, and forage. In addition, they form a good habitat for the honey bee to produce good quality honey (Aref *et al*. 2003). Only a few acacia species are used for firewood and charcoal production, while the others are a good source of browse, pole timber, gums, and tannins, *etc.* (Aref *et al*. 2003). The most popular acacia species of Saudi Arabia include *A. ehrenbergiana*, *A. tortilis*, *A. etbaica*, *A. asak*, and *A. gerardii* (Chaudhary 1983; Aref *et al*. 2003).

Structurally, wood cell walls are composed of cellulose, hemicelluloses, and lignin. The chemical composition of the wood varies widely, based on species and the position in the tree. Wood also contains varying amounts of extractives, which have a bearing on the characteristics of the wood and wood products (Fengel and Wengener 1989). Chemical composition is an important criterion for determining the suitability of a certain type of wood as fuelwood (Wang *et al*. 1981).

The heating value of the woody materials is determined primarily by the difference in the chemical constituents of the wood, which is influenced by genetic, physiological, and environmental conditions (Wang *et al*. 1981; Lemenih and Bekele 2004). Wood extractives vary greatly in their quantity as well as their chemical nature (Wang *et al*. 1981; Fuwape 1990; Kataki and Konwer 2002). It is believed that the variability of different woods' heating values is associated with variations in the characteristics of their extractives (Baker 1983).

Most of the research work done on acacia species in Saudi Arabia has dealt with silvicultural aspects (Aref *et al*. 2003) and environmental influences (Aref 2005). No information is available on the chemical composition and fuel properties of these species. Therefore, this study was undertaken to evaluate the fuelwood characteristics of six acacia species growing wild in two geographical locations in southwest Saudi Arabia and to investigate the relationship between the heating values and chemical constituents of the various woods.

EXPERIMENTAL

The current study was carried out in the forests of Abha (Capital of the Asir region) and Al-Baha (224 km north of Abha) during the year 2010. Samples of *A. asak*, *A. ehrenbergiana*, *A. etbaica*, *A. gerrardii*, *A. origina*, and *A. tortilis* were taken from five locations in the Al-Baha region. In addition, samples of *A. asak*, *A. etbaica*, *A. gerrardii*, and *A. origina* were also collected from the Abha region (Table 1). Due to the environmental considerations, only two trees were randomly selected for each species (24 trees in total). The ages of the selected trees ranged from 20 to 25 years. The dominant climate in the area is semi-arid. The monthly average rainfall is higher at Abha than at Al-Baha during the summer period (June to August), though the reverse is true for the rest of the year (El Atta and Aref 2010), as shown in Fig. 1. About 0.3-m-long bolts were cut along the grain at breast height with diameters of 8.24 to 13.95 cm. The bolts were covered with a moist cloth inside an ice box to reduce dehydration, then transferred to the

Forestry and Wood Technology Laboratory at the College of Food and Agricultural Sciences at King Saud University for further analysis. For each species, three zones on the disc (around the pith, at the middle, and near the bark) were analyzed for specific gravity, chemical analysis, and heating value determination. To prepare samples for chemical analysis and heating value determination, various samples from each zone were air-dried and ground individually in a Wiley mill, then passed through a 40-mesh screen and retained on a 60-mesh screen.

Table 1. Location of Sample Plots in the Study Area

		Coordinates		
Region	Location	N	E	Selected species
Al-Baha	Al-Ageeg	1949613	4134380	*Acacia etbaica*
	Al-Gimda	1949613	4135280	*Acacia origina*
	Al-Mechwa	50530	4136476	*Acacia asak*
	Kara Al-Ageeg Road	1946432	4137133	*Acacia ehrenbergiana*
				Acacia gerrardii
	Wadi Batat Namira Road	1953413	4137175	*Acacia tortilis*
Abha	Al-Marbaa Park	1754055	4226511	*Acacia gerrardii*
	Al-Masgaa Park	1764055	4228523	*Acacia origina*
	Beesha Park	1752056	4224511	*Acacia tortilis*
	Tihama-Ghtan	1749165	4224422	*Acacia etbaica*
				Acacia asak
	Al-Souda Road	1820097	4240794	*Acacia ehrenbergiana*

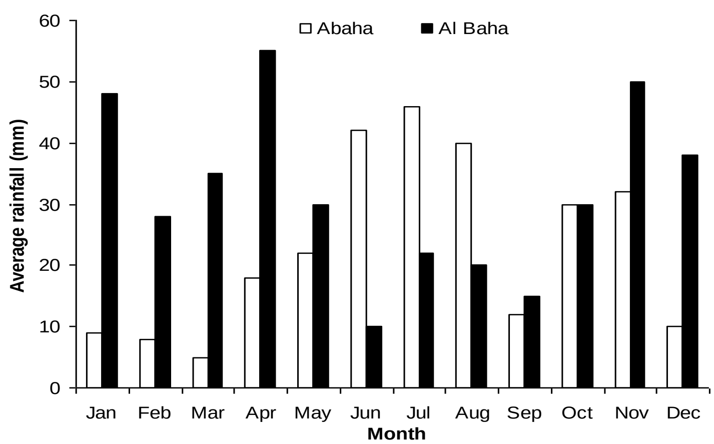

Fig. 1. Mean monthly rainfall distribution in Abha and Al Baha

Determination of Sapwood Percentage

The percentage of sapwood and heartwood was determined according to the method described by Nawrot (2008).

Heating Value Determination

To determine the heating value on a dry weight basis, approximately one gram of oven-dried ground sample (-40/+60 mesh) was pressed into pellet form and combusted in an oxygen bomb calorimeter (Model Parr 6300) according to ASTM D-2015 (1987). Correction factors for the formation of acids were not included in the heat calculations (Murphey and Cutter 1974). To minimize experimental error, an average of three combusted samples was taken as the estimated heat value. The fuel value index (FVI=

Heating value*specific gravity/ash content) was calculated using the method of Bhatt and Todaria (1990) with modifications. Corrections for the heat produced by the formation of nitric acid and sulfuric acid in the determination of heating values were not made because it accounted for only 0.1% of the resultant energy content because of the low biomass contents of nitrogen and sulfur (Senelwa and Sims 1999).

Specific Gravity Determination

For the determination of specific gravity, a disc was cut from each tree at breast height; thereafter, small specimens were cut from each disk with dimensions of 2X2X2 cm^3. Specific gravity was then evaluated using the green volume by displacement in water and oven-dry weight based on ASTM D 2395 (ASTM 1037, 1989).

Chemical Analysis of Wood

The extractives content of wood based on the oven-dry weight of the wood sample was determined in terms of percentage according to ASTM D1105 (ASTM D 1037, 1989). The contents of the three chemical components of wood, *i.e.*, cellulose, hemicelluloses, and lignin, were then determined for each wood species using wood meal free-extractive and based on oven-dry weights, according to the standard methods described in the ASTM D 1037 (1989). In addition, ash content was determined based on the oven-dry wood meal weight according to ASTM D 1102 (ASTM D 1037, 1989).

Statistical Analysis

Analysis of variance (ANOVA), using randomized complete design, was applied to determine the statistical differences between the heating value and the chemical component values of the wood among the six acacia species and the two locations, as well as within the species among the three positions extending from pith to bark. The results were analyzed using Statistical Analysis System, SAS. The least significant difference test at a 5% level of probability was used to detect the differences between the means of the heating value and the contents of the chemical components (extractives, cellulose, hemicellulose, lignin, and ash). Regression analysis was carried out to find correlations between the heating value and each of the chemical constituents of the wood.

RESULTS AND DISCUSSION

The trees of all six acacia species grown in the Abha region were slightly smaller in diameter at breast height (DBH) in comparison to those in the Al Baha region. It is clear from Table 2 that the mean DBH of the six species ranged from 8.24 cm (*A. ehrenbergiana*) to 13.95 cm (*A. gerrardii*). The lowest value of specific gravity (0.59) was obtained for *A. origina,* while the highest one (0.85) was obtained for *A. ehrenbergiana*. The sapwood percentage of the species studied ranged between 70.41 % for *Acacia etbaica* and 85.62 % for *Acacia gerrardii* in both study regions (Fig. 2).

Heating Values of the Species

Heating value (MJ per kg of oven-dry weight sample) is a measure of the basic thermo-chemical property of an organic material and is normally used for comparison between fuels (Wang *et al*. 1981). The chemical components and heating values of the six acacia species studied are presented in Table 3.

Table 2. Average* and Standard Deviations of Specific Gravity of Wood, Height, Diameter of Trunk at Breast Height (DBH), and Crown Diameter (CD) of Sample Trees

Species	Specific gravity**	Height (m)	DBH (cm)	CD (m)
Acacia asak (AA)	0.731±0.03	7.35±1.35	13.10±2.15	6.75±2.15
Acacia ehrenbergiana (AE)	0.846±0.11	4.21±0.95	8.24±1.54	6.41±1.44
Acacia etbaica (AET)	0.794±0.09	8.47±1.79	12.08±2.33	7.15±3.02
Acacia gerrardii (AG)	0.714±0.07	6.31±1.03	13.95±1.65	4.53±1.34
Acacia origina (AO)	0.585±0.06	5.84±2.21	12.41±2.46	3.32±0.95
Acacia tortilis (AT)	0.719±0.10	6.82±1.93	10.90±1.78	7.14±2.21

*Each value is an average of 2 samples, except for density, which is an average of 6 samples.
**Based on oven-dry weight and green volume (measured by the displacement method)

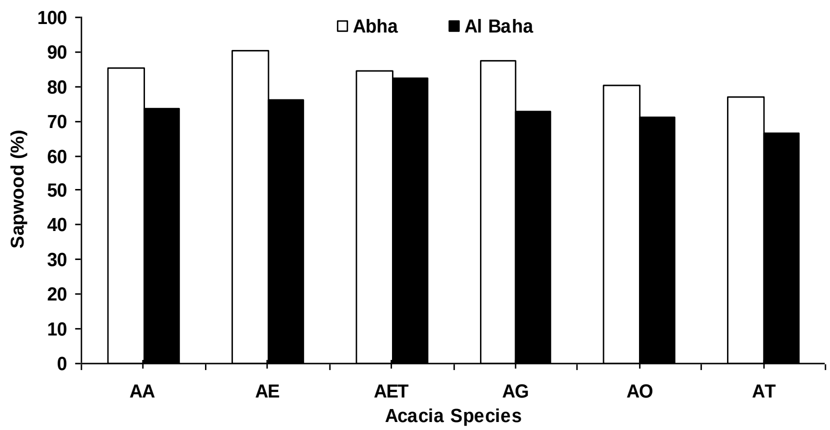

Fig. 2. Percentage of sapwood content in acacia species growing at the two study sites. For legend, see Table 2.

Table 3. Chemical Composition and Heating Value of the Wood of Six Acacia Species

Species	Wood component (%)					Heating value
	Extractives	Cellulose	Hemicelluloses	Lignin	Ash	(MJ kg^{-1})
Acacia asak	12.84±2.5^B	49.60±0.97^B	19.66±0.93^D	30.74±0.50^B	2.37±1.19^B	19.42±0.19^B
Acacia ehrenbergiana	9.94±2.3^D	50.69±0.76^A	20.82±0.92^C	28.40±1.22^F	2.78±0.53^A	18.00±0.46^E
Acacia etbaica	11.83±2.2^C	48.87±1.01^C	21.37±0.86^B	29.77±1.04^C	2.35±0.25^B	19.14±0.34^C
Acacia gerrardii	12.89±2.7^B	45.44±0.98^E	25.21±0.41^A	29.44±0.88^D	2.02±0.23^C	19.36±0.41^B
Acacia origina	9.48±1.9^E	45. 54±1.93^E	25.32±1.91^A	29.06±1.07^E	1.99±0.17^C	18.24±0.42^D
Acacia tortilis	13.82±1.8^A	46.92±0.56^D	21.10±1.26^{BC}	31.81±1.68^A	1.94±0.49^C	20.45±0.67^A

Each value is an average of 18 samples.
Means followed by the same letter in each column are not significantly different at the 5% level.

The analysis of variance revealed highly significant interspecific differences in the heating value and chemical composition of the wood, suggesting that the species in question are statistically different. The least significant difference test indicated that the gross heating value depends on the chemical composition of the wood. This conforms to the findings of Kataki and Konwer (2002) for certain Indian woody species and those of Senelwa and Sims (1999) for selected New Zealand woods. Among the species studied, the wood of *A. tortilis* had the highest heating value (20.45 MJ kg^{-1}), followed by both *A.*

gerrardii and *A. asak* (19.36 and 19.42 MJ kg^{-1}, respectively), while *A. ehrenbergiana* had the lowest value (18.00 MJ kg^{-1}), as seen in Table 3. These values are within the range reported in the literature for hardwood species (Panshin and DeZeeuw 1980) and the one given by Arola (1976), *i.e.*, 16.26 to 23.97 MJ kg^{-1}. These values are also close to the theoretical mean heating value for hardwoods (19.54 MJ kg^{-1}), as mentioned by Neenan and Steinbeck (1979).

Chemical constituents of the wood differed significantly among the species studied (Table 3). The extractives content ranged from 9.94% (*A. ehrenbergiana*) to 13.84 % (*A. tortilis*). The amount and nature of extractives soluble in water and organic solvents vary widely from one species to another. They are more abundant in the heartwood than in the sapwood and are affected by the tree's age (Kollman and Cote 1968). The results confirm that the wood with higher extractive and/or lignin contents often have a high heating value. Here, *A. tortilis* had the highest extractive and lignin contents (13.82 % and 31.81%, respectively) as well as the highest heating value (20.45 MJ kg^{-1}). On the other hand, *A. ehrenbergiana* had the lowest lignin value (28.4%) and low extractive content (9.94%) and also the lowest heating value (18.0 MJ kg^{-1}). This could be because extractives and lignin have a higher heating value of 23.26 to 25.59 MJ kg^{-1} compared to cellulose and hemicellulose, which both have a heating value of 18.61 MJ kg^{-1} (Baker 1983). Senelwa and Sims (1999) reported that the high heating values of leaves (21.8 MJ kg^{-1}) is caused by the higher content of extractives (32.9%) compared to wood and bark, whose extractives contents were 5.5 and 9.8%, with corresponding heating values of 14.5 and 18.5 MJ kg^{-1}, respectively. The sum of chemical composition (total extractives, cellulose, hemi-cellulose, and lignin) was more than 100% (*i.e.*, *Acacia asak* 112.84%); this is a common result, due to the overlapping of the test results (Anglès *et al.* 1997).

Table 3 shows that the ash content of acacia wood varied significantly, ranging from 1.94% (*A. tortilis*) to 2.78% (*A. ehrenbergiana*). Normally, the ash content for wood ranges from 0.1% to 0.5% in tree species (Panshin and DeZeeuw 1980). The higher values obtained here could be explained by the fact that tropical wood species need more mineral elements for growth than other woods (Chow and Lucas 1988). Therefore, these trees absorb more mineral elements from the soil and store them in cell walls and cell cavities. The results are in agreement with those of Kataki and Konwer (2001), who attributed the relatively lower heating content of the bark to the higher amount of ash-forming materials present in the bark; removing ash from the plant parts (heating value based on ash-free basis) was found to increase their heating values. In general, ash content is an unfavorable factor that needs to be controlled during the direct combustion of wood (Chow and Lucas 1988). High-quality lump charcoal typically has an ash content of about 3% (FAO 1985). Most of the acacia species studied here meet the standard specifications published by FAO (1985).

The results show that *A. ehrenbergiana* had the lowest heating value among the acacia species studied, although this is the most preferred acacia species in the Kingdom of Saudi Arabia for firewood. This might be explained by the fuel value index (Fig. 3), where *A. ehrenbergiana* occupies the top position, indicating that it has high energy content per unit volume and a slow burning rate. This is in agreement with the findings of Kataki and Konwer (2002) and Khoo *et al*. (1982), who reported that denser species are preferable for fuel because of their high energy content per unit volume and slow burning rates. In the current study, the specific gravity of wood varies among the six acacia species, ranging from 0.585 for *A. origina* to 0.846 for *A. ehrenbergiana* (Table 2).

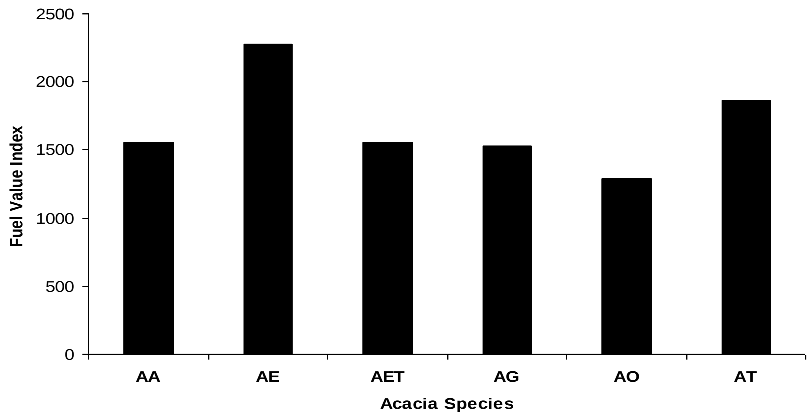

Fig. 3. Fuel value index of six acacia species. For legend, see Table 2.

Heating Values as Influenced by Geographic Location

Table 4 shows the mean values of the chemical constituents and heating values of the six acacia wood from two locations (Abha and Al Baha regions) in southwest Saudi Arabia. The inter-location differences were highly significant for extractives, lignin, and hemicellulose contents as well as the heating values of the wood. However, differences were not significant for cellulose and ash contents (Table 4). The trees grown in the Al-Baha region exhibited higher heating values than those in the Abha region. This could be caused by the higher contents of extractive and lignin in the wood of the trees of the Al Baha region, as compared to those of the Abha region. These results substantiate the findings of Wang *et al.* (1981) on the *Melaleuca* biomass, which indicated that the trees from the Lee Country region had a better fuel quality than those from the Dade Country region (19.51 and 19.09 MJ kg^{-1}, respectively).

Table 4. Chemical Composition and Heating Value of the Six Acacia Wood at Two Locations

Species	Location	Wood component (%)					Sapwood	Heating value
		Extractives	Cellulose	Hemicell	Lignin	Ash	(%)	(MJ kg^{-1})
Acacia asak	Abha	12.55 (1.7)	50.17 (0.7)	19.03 (0.81)	30.80 (0.5)	2.26 (1.0)	85.51 (2.0)	19.31 (0.17)
	Al-Baha	13.13 (3.2)	49.03 (0.8)	20.29 (0.53)	30.68 (0.5)	2.44 (0.4)	73.70 (4.6)	19.53 (0.14)
Acacia ehrenbergiana	Abha	8.62 (2.4)	50.39 (0.9)	20.95 (0.70)	28.46 (1.3)	2.97 (0.1)	90.24 (3.9)	17.88 (0.36)
	Al-Baha	11.26 (1.2)	50.98 (0.5)	20.68 (1.14)	28.34 (1.2)	2.59 (0.2)	76.01 (4.1)	18.11 (0.54)
Acacia etbaica	Abha	10.09 (0.9)	49.59 (0.8)	20.81 (0.73)	29.60 (1.3)	2.27 (0.1)	84.38 (2.3)	19.07 (0.32)
	Al-Baha	13.57 (1.6)	48.14 (0.6)	21.93 (0.58)	29.92 (0.8)	2.47 (0.3)	82.44 (5.8)	19.18 (0.36)
Acacia gerrardii	Abha	10.50 (1.3)	45.38 (0.9)	25.26 (0.30)	29.36 (0.7)	1.99 (0.2)	87.34 (4.0)	19.00 (0.26)
	Al-Baha	15.28 (1.2)	45.49 (1.1)	25.15 (0.51)	29.53 (1.1)	2.06 (0.3)	72.50 (2.1)	19.70 (0.14)
Acacia origina	Abha	8.91 (1.3)	43.86 (0.8)	27.07 (0.71)	28.88 (1.3)	2.10 (0.2)	80.40 (3.7)	17.91 (0.19)
	Al-Baha	10.05 (0.8)	47.22 (1.0)	23.58 (0.66)	29.23 (0.9)	1.89 (0.1)	71.72 (5.1)	18.56 (0.32)
Acacia tortilis	Abha	12.24 (1.7)	47.03 (0.7)	22.22 (0.64)	30.41 (1.2)	1.84 (0.4)	76.78 (2.7)	19.89 (0.46)
	Al-Baha	14.53 (0.9)	46.82 (0.5)	19.97 (0.37)	33.21 (0.4)	2.04 (0.6)	66.32 (3.3)	21.00 (0.25)
$LSD_{0.05}$		**0.37**	**0.42**	**0.40**	**0.38**	**0.17**	**2.65**	**0.12**

Each value is an average of 9 samples; ( ): values in brackets are the standard deviations.
$LSD_{0.05}$ is least significant difference at the 5% level of probability.

Alder *et al.* (2008) reported similar observations for shoot biomass yield and the total energy content of two populations of *Salix viminalis.* Table 4 shows that the trees contained a greater proportion of sapwood at the Abha than at the Al Baha sites. It is known that heartwood contains a greater extractive and lignin percentage, which results in higher heating values (Fuwape 1990; Lemenih and Bekele 2004).

Heating Value Variations from Pith to Bark

The chemical constituents and the heating values of the wood at different distances from pith to bark are presented in Table 5. Statistically, the differences among three zones, *i.e.*, around the pith, at the midpoint, and near the bark across the wood core radius (from pith to bark), were highly significant for extractives, lignin, ash contents, and the heating values of the wood, and significant for cellulose and hemicellulose contents. The extractive and lignin contents significantly decreased in the radial direction along the wood core radius. The same pattern was observed for the heating values of the wood. However, a reverse pattern was observed for the cellulose and hemicellulose contents. No regular trend of variation was observed for the ash content. The increase in the heating value might be attributed to increasing amounts of extractives and lignin in the same direction. This correlation may also be related to the presence of juvenile wood, which is located near the pith and has a higher extractive and lignin content than mature wood (Evans and Senft 2000; Guler *et al*. 2007). Fuwape (1990) found a significantly higher heating value for the heartwood of *Gmelina arborea* than for its sapwood. However, the reverse was true for cellulose and hemicellulose contents. A direct relationship between heating values and each of the extractives and lignin contents (R^2= 0.68 and 0.70, respectively) is shown in Figs. 5 and 6. Similar results showing a decrease in the extractives content and heating value from pith to bark were obtained by Hindi (1994) for four hardwood species grown in Egypt.

Table 5. Mean Values* of Chemical Components and Heating Values along the Wood from Pith to Bark

Wood	Wood component (%)					Heating value
Zones	Extractives	Cellulose	Hemicelluloses	lignin	Ash	(MJ kg^{-1})
Near bark	10.23^c	48.27^a	22.69^a	28.94^c	2.28^b	18.83^c
Middle point	11.49^b	48.08^a	22.02^b	29.81^b	1.99^c	19.09^b
Near pith	13.46^a	47.17^b	22.03^b	30.85^a	2.45^a	19.39^a

* Each value is an average of 36 samples.
Means followed by the same letter in each column are not significantly different at the 5% level.

Relationship between Heating Values and Chemical Components

In the second stage of this analysis, multiple regressions were used to reach the full model, and the best reduced model representing the relationship studied was extracted from the full model using a type of backward elimination procedure (Snedecor and Cochran 1967). The choice of the best reduced model was based on the significance of each term as well as the coefficient of determination, R^2 (Draper and Smith 1967).

The relationship between the heating value and each of the extractives and lignin contents is shown in Figs. 4 and 5. The results indicate a high positive correlation of the heating value to the extractives content (R^2=0.56, Fig. 4) and lignin content (R^2=0.70, Fig. 6), as mentioned by some researchers (Megahed 1992; Vos 2005). The increase in heating value must be caused by the increased extractive and lignin contents, which have higher heating values relative to the cellulose and hemicellulose contents. The mean difference in the heating values of softwoods and hardwoods is said to be caused primarily by their difference in lignin contents (White 1987). According to Baker (1983), cellulose and hemicellulose have a lower heating value of 18.64 MJ kg^{-1}, whereas that of lignin is higher (23.30 to 25.64 MJ kg^{-1}). Vos (2005) reported that lignin is rich in carbon and hydrogen, the main heat-producing elements, and therefore has a higher heating value than carbohydrates (cellulose and hemicellulose). Howard (1973) found that the alcohol/benzene extractive content of loblolly pine positively correlated to the heating value (R^2 = 0.54). The extractives of different parts of *Gmelina arborea* positively contributed to the heating value, and the removal of the extractives caused a reduction in the heat of combustion (Fuwape 1990).

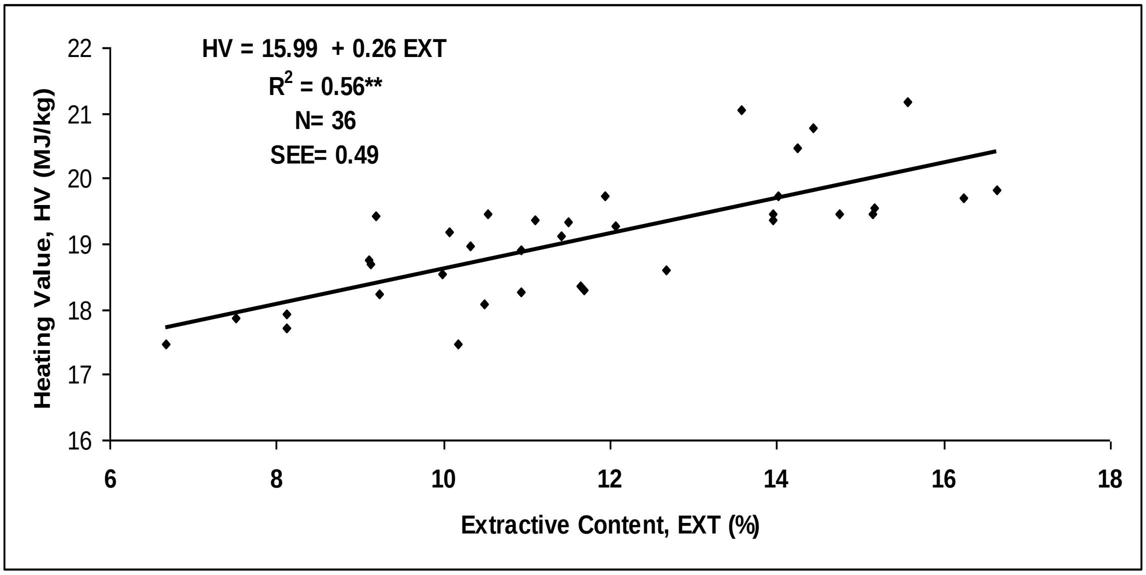

Fig. 4. Heating value of acacia wood *versus* extractive content

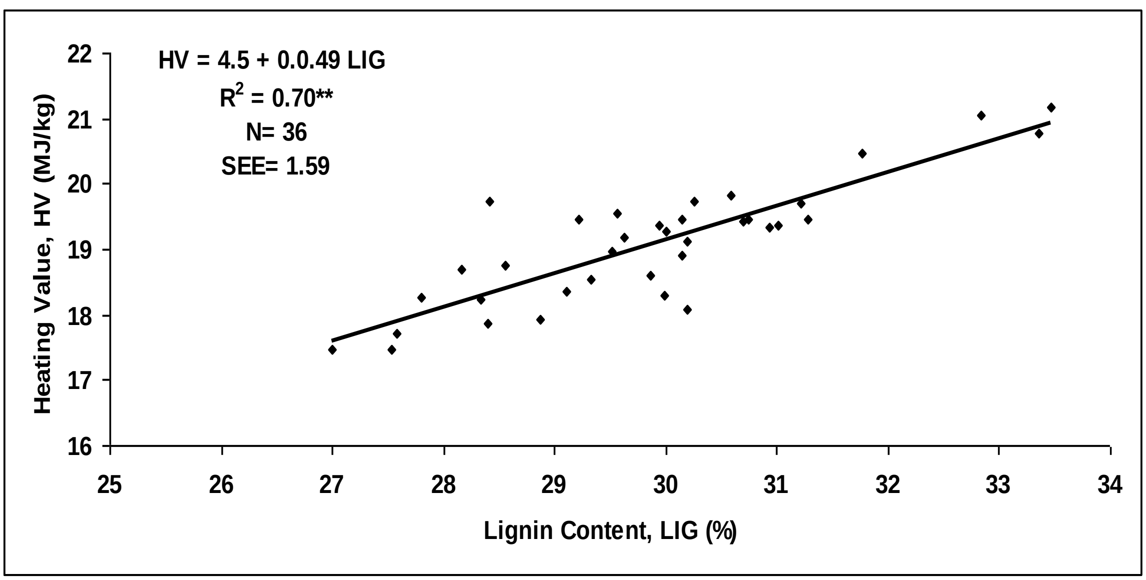

Fig. 5. Heating value of acacia wood *versus* lignin content

The results indicate that the contents of extractives and lignin are the major factors that influence the heating values of acacia woods. The interspecific differences in the heating values related more to lignin (r=0.84) than to extractives (r=0.75). The simple regression analysis shows that the trend of the data for all the acacia species studied is best described by the following simple linear regression equations, *i.e.*

$$HV = 15.99+0.26\ EXT\ (S_{EE} = 0.49 \text{ and } R^2 = 0.56)$$

$$HV = 4.50+0.49\ LIG\ (S_{EE} = 1.59 \text{ and } R^2 = 0.70)$$

where HV is the heating value of the wood (MJ kg^{-1}), EXT is the extractive content of the wood (%), LIG is the lignin content of the wood (%), and S_{EE} is standard error of estimate. It can be seen that there were significant differences in the slopes of the data. Approximately 56.3 % and 70.4 % of the total variability in the heating values of acacia wood was attributable to the extractives content and lignin content, respectively. Furthermore, multiple regression analysis between HV and the independent variables, extractive content and lignin content, resulted in the following equation:

$$HV = 6.15 + 0.11\ EXT + 0.39\ LIG\ (S_{EE} = 1.69 \text{ and } R^2 = 0.79)$$

This relationship reveals that about 79 percent of total variability in the heating value was attributable to the extractive and lignin contents.

CONCLUSIONS

1. The wood of *A. tortilis* had the highest heating value (20.45 MJ kg^{-1}), followed by *A. gerrardii* and *A. asak* (19.36 and 19.42 MJ kg^{-1}, respectively).
2. *A. ehrenbergiana* had the lowest heating value (18.0 MJ kg^{-1}) among the species studied, although it is the most preferred acacia species for fuelwood in the Kingdom.
3. The differences between the extractives, lignin, and hemicellulose contents and the heating values of samples from the two geographical locations (Abha and Al-Baha) were highly significant.
4. Wood from the Al-Baha region had greater heating values than those from the Abha region.
5. The amounts of extractives and lignin, as well as the heating values, significantly decreased across the wood radius from pith to bark.
6. The extractives and lignin contents were the main factors affecting the heating values of acacia wood.
7. The heating value had a high positive correlation with the extractives content (R^2=0.56) and lignin content (R^2=0.70).

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