Fuel Characteristics of Vine Prunings (*Vitis vinifera* L.) as a Potential Source for Energy Production

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Seven varieties of vine prunings (*Vitis vinifera* L.) grown under Riyadh conditions were considered as renewable sources for fuelwood. Significant effects (P<0.01) were found for total extractives, benzene-ethanol extractives, cellulose, hemicellulose, lignin, cold water solubility, and hot water solubility among the seven vine varieties. Highly significant positive correlations (P<0.01) were observed between the higher heating value (HHV) and benzene-ethanol extractives (r=0.74) and lignin content (r=0.94). Additionally, elemental composition (C, H, N, O, and S) exhibited a significant effect on HV (P<0.01) and ash content of the seven vine varieties. There were highly significant positive correlations (P<0.01) between the HV and C (r=0.96) and H (r=0.93). Ash content showed a highly significant effect (P<0.01) on HV with a negative coefficient (r=-0.93). The heating value of vine prunings ranged from 18.74 to 19.19 MJ/kg, *i.e.* higher than some well-known biomass fuels. The results suggested that the vine prunings could be suitable as a source for energy production in Saudi Arabia.

Keywords: Vine prunings; Heating value; Elemental composition; Biomass-fuel; Environmental problems

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INTRODUCTION

Alternative sources of fuelwood are not easily accessible for rural inhabitants, due to poor connectivity with the urban areas. Consequently, the population is totally dependent on wood resources (Bhatt and Sachan 2004), and it is evident that most of this demand is met from the adjoining forests, leading to depletion. Biomass extraction, *i.e*. its usage as fuelwood and fodder, is the major reason for such loss of forested land (Husen and Nautiyal 2004). However, technically and economically sound procedures already exist for reforestation and for improving the efficiency with which wood and other biomass fuels are burnt (Negi and Todaria 1993).

The first and most important source of fuel used by humans for thousands of years has been wood harvested from trees and shrubs. During the last four decades, the utilization of wood as a source of energy has significantly increased. On the other hand, increasing concern for the environment and climate change has resulted in significant reductions in wood harvest from the national forests in the midst of growing demands (Ye *et al*. 2007). In the meantime, the use of wood for energy has declined due to the harnessing of fossil and nuclear fuels. However, it is still a major source of energy in both the developed and developing countries (FAO 2005). Therefore, the shortage of fuelwood is being felt at the national and global levels. When fuel is in tight supply, the population can be expected to use any available wood species for fuelwood without regard to other issues, such as the sustainability of the species and/or to the impact of the species on the environment (Kumar *et al*. 2009). In addition, depending on such factors, such as different altitudes and the local patterns of fuelwood consumption, it is imperative to consider the problem of deforestation. The past few decades have witnessed the loss of forest cover owing to population rise, construction of roads, and market forces (Awasti *et al*. 2003).

To overcome the fuelwood shortage and to meet future demands, studies have investigated the utilization of non-wood materials, agricultural residues, fast-growing trees, low-grade wood species, and/or underutilized wood species for energy production in several countries. The use of these materials is a way of saving wood. Also, researchers have been focusing on alternative fuel sources to meet the ever-increasing energy demand and to avoid dependence on crude oil. Recently, global interest in renewable energy sources, especially energy from biomass, has grown significantly (Bilandzija *et al*. 2012). Furthermore, biomass is a renewable resource that is widely available and has a good potential as a source of energy, such as electricity and heat, as well as liquid fuels, which are practical and easy to use (Hoogwijk *et al*. 2009). There have been continuous efforts to find new renewable resources as alternatives to wood harvested from natural forests for energy production. A wide variety of these materials have been investigated, *i.e*. tobacco stems (Pesevski *et al*. 2010), rice waste (Salleh *et al.* 2011), common reed (Kitzler *et al*. 2012), switch grass and coffee weed (Ismaila *et al*. 2013), and date palm seeds (Babiker *et al*. 2013).

There are many factors affecting the quality of a raw material for fuelwood production. The most important factors are heating value, density, ash content, and elemental and chemical composition. The heating value, which is a measure of the thermo-chemical energy, has been found to range from 17 and 22 MJ/kg based on oven-dried wood and could be related to its chemical composition (Fengel and Wegener 1993). Previously, Friedl *et al*. (2005) reported that the following elements, C, H, N, O, and S are the major elements contributing to the calorific value. Additionally, the analysis of elements is a functional way to describe biomass fuels, and determine their calorific values and their expected impact on the environment (Munalula and Meincken 2009; Bilandzija *et al*. 2012). Additionally, high ash content is undesirable as fuel. A higher wood density increases the heating value and tends to slow the burning rate (Fuwape and Akindele 1997). On the other hand, the presence of moisture in the biomass negatively affects the heating value (Kataki and Konwer 2001). The hardwood species show a higher ash content than the softwoods, although they have higher heating values (Munalula and Meincken 2009).

The area of the natural forests in the kingdom of Saudi Arabia is about 2.1 million hectares, representing approximately 1.3% of the total area of the kingdom (El Atta and Aref 2010). This means that Saudi Arabia, like many countries in arid and semi-arid regions, is poor in natural forests and it depends on the import of timber to meet the demands of its population (Nasser *et al*. 2012). Saudi Arabia relies heavily on fuelwood as a main energy source for cooking and heating purposes in homes and leisure trips in open places with family, and therefore the consumption of fuelwood is bound to increase greatly.

The consumption of fuelwood was about 179 thousand m^3 in 2000 and increased to about 261 thousand m^3 in 2012 (FAOSTAT 2013). The same trend was observed for wood charcoal, which increased from 67 to 117 thousand tones, respectively (FAOSTAT, 2013).

Fortunately, Saudi Arabia has relatively large quantities of lignocellulosic materials, including the vine prunings available in the form of agricultural residues. A large vine production in Saudi Arabia sheds a huge quantity of residues annually as a result of seasonal pruning, which is an essential agricultural practice. Though there are no actual studies on the amount of vine pruning residues per year, it can be estimated that about 3 to 8 kg of biomass per tree is wasted annually from seasonal pruning of the vine grape, depending on the variety, soil type, region, and agricultural treatments. In the developed countries, these residues are used to produce valuable wood-based panels such as particleboard and medium density fiberboard (MDF), although in most of the developing world these are simply burnt to ash (Nasser *et al.* 2011).

The lignocellulosic prunings of *Vitis vinifera* L. are considered to be agricultural-residues, and they could replace wood in the production of fuelwood. Large quantities of vine prunings that remain unused in the fields every year after the pruning season could be pressed into briquettes to produce biofuels, or fiberboards or particleboards, therefore adding value to the waste (Mancera *et al*. 2011a,b, 2012; Ntalos and Grigoriou 2002). Tsai *et al*. (2006) explained that the grape residues are composed of a large amount of cellulose and hemicelluloses with high energy content. Vine stumps and prunings are by-products of vine plantations, and large quantities of vine stumps are commercially sold as firewood.

The drawback is their low calorific value (18.73MJ/kg) and density (around 597.37 kg/m^3, which reduces their potential for utilization in a larger setup) (Munalula and Meincken 2009). Vine stumps also have a relatively low density of about 500 kg/m^3, which contributes to the high ignition and combustion rate (Tsai *et al*. 2006).

The objective of the present study was to evaluate the fuel characteristics as an alternative source for energy production from the prunings of seven vine varieties planted at the Agricultural Experimental Station, Riyadh, Saudi Arabia.

EXPERIMENTAL

Preparation of Prunings Materials

Pruning residues of vine grown under Riyadh conditions were collected from the seasonal prunings of seven vine varieties (*Vitis vinifera* L.) planted at the Agricultural Experimental Station near Derab, 60 km south of Riyadh in Saudi Arabia during December 2011. The site has the following characters: 24^o 6' N, latitude; 46^o 5' E, longitude; temperature (as an average of season) ranged between 10 °C in winter and 41 °C in summer; 50 mm rainfall annually and calcareous soil. The seven vine varieties were Soltany, Halwany, Flame seedless, Kamaly, Red Globe, Thompson seedless, and Black Monica.

After air drying, the prunings were cut, ground, and screened. Particles that had been ground to pass through a 20 mesh screen and be retained on a 40 mesh screen were used to determine the fuel characteristics, while those particles that were passed through 40 mesh screen and retained on a 60 mesh screens were used for chemical and ultimate analysis of the vine prunings.

Physical Properties

For moisture content and wood density determination, ten specimens were randomly taken from each vine variety, weighed, coded, and aspirated under vacuum until water-logged. The saturated weight was recorded, and the oven-dry weight of each specimen was obtained in an oven at 103 °C to constant weight. The basic density of each specimen was determined according to the maximum moisture content method by using the equation developed by Smith (1954). The percentage moisture content of the vine prunings (green basis) was determined by using the conventional oven-dry method. Ten small discs were randomly selected to determine the weight proportion of bark, wood, and pith of the prunings from each vine variety based on dry weight (Ntalos and Grigoriou 2002).

Chemical Analysis

The percentage content of total extractive was determined based on oven-dry weight of sample for the vine prunings of the seven vine varieties according to the standard method outlined in ASTM D 1105-84 (1989). Using vine meal free-extractive and based on oven-dry weights, the contents of the cellulose, hemicelluloses, and lignin were determined for each vine variety according to the methods described in the ASTM standard (1989).

Ultimate Analysis

Ultimate analysis includes elemental analysis and ash content. Elemental contents of the vine pruning from the seven vine varieties were analytically determined using a CHN analyzer, Perkin Elmer model 2400. The contents of carbon (C), hydrogen (H), nitrogen (N), and sulfur (S) were determined as a percentage, while the percentage of oxygen (O) content was calculated by subtraction from 100. Ash content was determined according to ASTM D 1102-84 (1989). Briefly, approximately 2 g of vine particles (40 to 60 mesh) were ignited in a muffle furnace at 575±25 °C for 6 h to eliminate all of the carbon of the sample. Ash contents as a percentage based on the oven-dry weight of the sample and biomass/ash ratio were calculated.

Heating Value

Heating values (HV) of the prunings from the seven vine varieties were determined on dry weight basis according to the standard method described in ASTM D 2015-85 (1987). Approximately one gram of oven-dried ground sample (20 to 40 mesh) was converted into pellets using a hydraulic pellet press and loaded into an oxygen bomb calorimeter, Parr model 6300. Before the analysis of the samples, the calorimeter was calibrated using standard benzoic acid (Kumar *et al*. 2009). However, no correction for acid formation was included in the heating value calculations. Six samples from each vine variety were combusted to estimate the heating value. The fuel value index, FVI, was calculated using a modified method of Bhatt and Todaria (1992), FVI= HHV*Density/ash content. Higher heating value (HHV) refers to the heating value determined by using calorimeter based on oven-dry weight. The lower heating value (LHV), which is also called HV as received (ar), was calculated by using the equation: LHV= HHV (1-moisture content/100). Dry ash-free fuel (daf) was calculated by using the equation: HHV (1+ash content/100).

Ranking of Vine Prunings

The seven varieties of vine were rated based on the positive and/or negative impacts on the energy content and environmental impact; the property was assigned a value between 1 and 7, with 1 being the best and 7 being the worst according to Munalula and Meincken (2009). The rating was calculated as the sum of all values divided by the number of measured properties (**Σ**/10). Rating value refers to energy output and environmental impact.

Statistical Analysis

Data were analyzed by using a complete randomized design (CRD) to detect the statistical differences among the seven vine varieties. The analysis of variance (ANOVA) was used to test the differences between the seven vine varieties in all the measured properties. Least significant differences at 0.05 level of probability ($LSD_{0.05}$) was used to detect the differences among the means of all the measured properties. Correlation analysis was used to determine the relation between the heating value and each of the chemical constituents and ultimate analysis of the vine prunings.

RESULTS AND DISCUSSION

Physical Properties of Vine Prunings

Table 1 shows the physical properties (MC% and density) and weight proportion of the received samples of vine prunings from the seven varieties. The MC values of the seven measured vines ranged from 42.17% (Kamaly) to 64.33% (Red Gloub). The highest wood density was observed for Halwany with 802 kg/m^3, where the lowest values were found for Black Monica (541 kg/m^3). Previously, Munalula and Meincken (2009) reported that *V. vinifera* had a density of 597.37 Kg/m^3 with an average heating value 18.73 MJ/kg.

Table 1. Physical Properties and Weight Proportion of the Studied Seven Vine Prunings

Vine Varieties	MC	Wood Density	Weight Proportion (%)		
	(%)	(kg/m^3)	Wood	Bark	Pith
Soltany	56.11ab	734ab	83.5c	11.2d	5.3ab
Halwany	66.00a	802a	83.7c	13.9b	2.4c
Flame seedless	49.17bc	578c	80.9d	12.7c	6.4a
Kamaly	42.17c	761ab	78.9e	14.3ab	6.8a
Red Globe	64.33a	756ab	87.6b	8.8e	3.6bc
Thompson seedless	50.26bc	724b	89.3a	7.6f	3.0c
Black Monica	49.47bc	541c	81.2d	15.0a	3.8bc

Moisture content, MC is based on wet basis.
Density of vine wood is based on oven-dry weight and volume.
Means with the same letters within the same column are not significantly differences according to $LSD_{0.05}$ test.

In order to specify the properties of the raw materials, the highest values of weight proportion from different parts analyzed (wood, bark, and pith), were shown in wood, followed by bark, and the lowest in pith. For example, in the vine variety Soltany, the weight proportions of wood, bark, and pith were 83.5%, 11.2%, and 5.3%, correspondingly. Additionally, from the studied varieties it can be seen that the vines Thompson seedless, Black Monica, and Kamaly had the highest amount of wood, bark, and pith with 89.3%, 15.0%, and 6.8%, respectively. In a parallel manner, Kamaly, Thompson seedless, and Halwany had the lowest amounts of wood, bark, and pith with 78.9%, 7.6%, and 2.4%, respectively.

Chemical Composition of Vine Prunings

Statistically, it was demonstrated that there were significant differences (P<0.01) of total extractives, benzene-ethanol extractives, cellulose, hemi-cellulose, lignin, cold water solubility, and hot water solubility among the seven vine varieties. The average chemical compositions of the received materials are shown in Table 2. The sum of chemical composition (total extractives, cellulose, hemi-cellulose, and lignin) was more than 100% (*i.e.*, Soltany 118.04%); this is a common result (the material was air dried, stored, and the prunings branches were chipped), due to the overlapping of the test results (Anglès *et al.* 1997).

Table 2. Average Chemical Composition of Vine Prunings from Seven Varieties of *Vitis vinifera* Compared to Literature Results

Vine Varieties	Chemical Composition (%)					Solubility (%)	
	Total Extractives	Benzene-ethanol[1]	Cellulose[2]	Hemi-cellulose[2]	Lignin[2]	Cold water[3]	Hot water[3]
Soltany	18.05d	3.66b	39.13a	32.91bc	27.95b-d	10.18e	13.80e
Halwany	20.87b	3.94b	39.03a	31.91cd	29.01ab	12.25cd	15.70b
Flame seedless	21.03b	4.02b	39.71a	31.05d	29.23ab	13.12e	14.70de
Kamaly	19.66c	2.79c	39.40a	33.91ab	26.68d	11.74d	15.14bc
Red Globe	26.13a	5.54a	36.77b	33.05bc	30.18a	15.78a	19.59a
Thompson seedless	17.76d	4.01b	39.32a	32.06cd	28.61bc	12.86bc	14.60cd
Black Monica	19.20c	3.50b	38.01ab	34.65a	27.35cd	12.31cd	14.82c
Correlation with HV[4]	0.34^{ns}	0.74^{**}	-0.32^{ns}	-0.67^{ns}	0.94^{**}	0.68^{ns}	0.51^{ns}
Hardwood[5]	-	-	40-44	15-35	18-25	-	-
Softwood[5]	-	-	40-44	20-32	25.35	-	-

Means with the same letters within the same column are not significantly differences according to LSD test.
1: Benzene-ethanol was done by using a mixture of them 2:1 v/v, respectively for four hours.
2: As a percentage of free-extractive oven-dry weigh.
3: As a percentage of oven-dry weigh.
4: Correlation coefficient, ns: not significant and ** highly significant at 0.01 level of probability. HV is heating value on dry weight basis.
5: Data from Fengel and Wegener (1993).

Table 2 shows that the total extractives, benzene-ethanol extractives, cellulose, hemicellulose, lignin, cold water solubility, and hot water solubility ranged from 18.05% (Soltany) to 26.13% (Red Globe), 2.79% (Kamaly) to 5.54% (Red Globe), 39.71% (Flame seedless) to 36.77% (Red Globe), 31.05% (Flame seedless) to 34.65% (Black Monica), 27.35% (Black Monica) to 30.18% (Red Globe), 10.18% (Soltany) to 15.78% (Red Globe), and 13.80% (Soltany) to 19.59% (Red Globe), respectively. *V. vinifera* chemical composition revealed medium cellulose and high lignin percentages in comparison to softwood and hardwood, as well as the results from existing literature

(Mancera *et al.* 2012). In the study of Mancera *et al.* (2011a), the average chemical composition of the initial material branches of *V. vinifera* was 3.7% ash, 13.3% extractives, 24% lignin, 43.6% cellulose, and 19.1% hemicellulose.

In this study, there were highly significant positive correlations ($P<0.01$) between the heating value (HV) and benzene-ethanol extractives ($r=0.74$) and lignin content ($r=0.94$), as shown in Fig. 1. The correlation was positively not significant ($P>0.05$) with total extractives ($r=0.34$) and the solubility in cold water ($r=0.68$) and hot water ($r=0.51$). On the other hand, the correlation was negatively not significant ($P>0.05$) with cellulose ($r=-0.32$) and hemicellulose ($r=-0.67$). These results are in agreement with Kataki and Konwer (2001), Munalula and Meincken (2009), and Kumar *et al.* (2009).

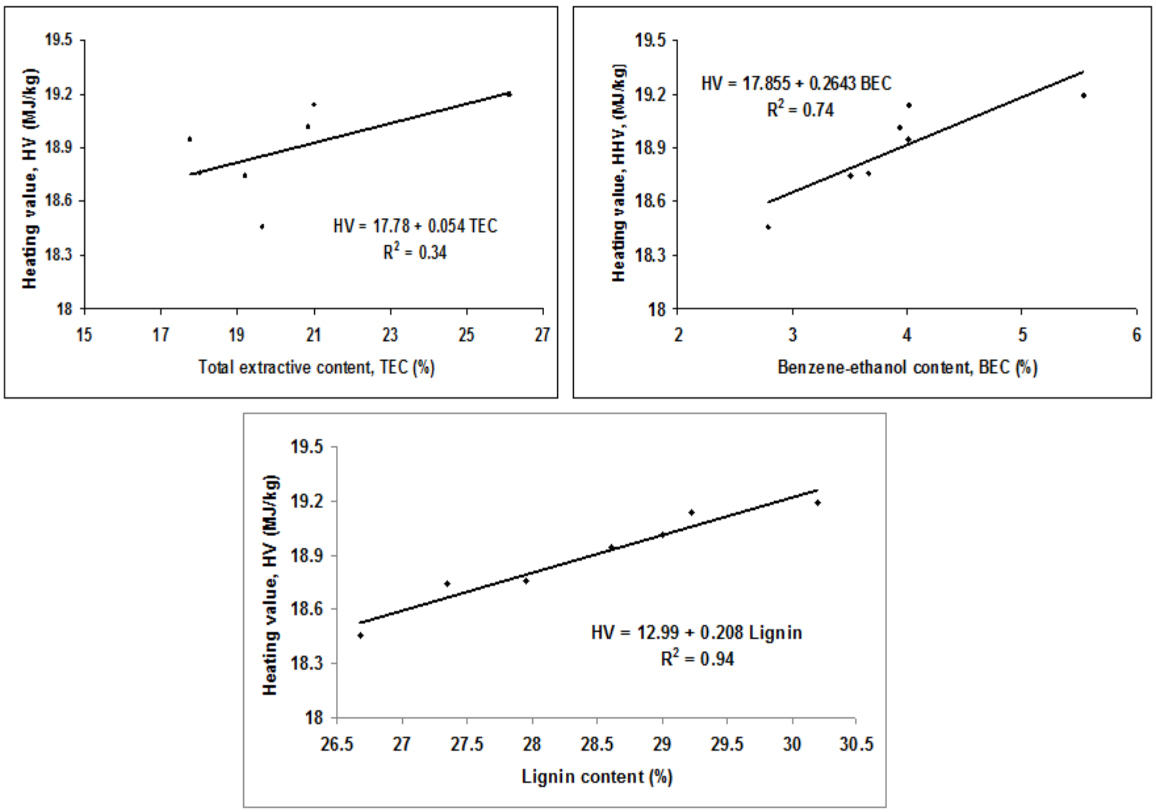

Fig. 1. Correlations between the measured heating values of the seven vine varieties and each of total extractives, benzene-ethanol extractives and lignin content

Ultimate Analysis of Vine Prunings

The average elemental components (carbon, hydrogen, nitrogen, oxygen, and sulfur) and ash content of the vine prunings compared with some woody plants is displayed in Table 3. According to ANOVA followed by $LSD_{0.05}$, there were significant differences ($P<0.01$) in the elemental components and ash content of the seven vine verities. The carbon, hydrogen, nitrogen, oxygen, and sulfur ranged from 46.64% (Black Monica) to 48.40% (Red Globe), from 5.50% (Black Monica) to 5.68% (Red Globe), from 0.78% (Kamaly) to 1.05% (Black Monica), from 0.009% (Kamaly) to 0.269% (Black Monica), and from 45.10% (Red Globe) to 47.02% (Soltany), respectively. The ash content ranged from 2.87% (Red Globe) to 4.12% (Kamaly).

A comparison of the elemental composition of the prunings of the seven varieties of *V. vinifera* with softwoods, and hardwoods is presented in Table 3. It is evident that the C content of vine prunings (46.64 to 48.40%) was lower than hardwoods (50.8%) and softwoods (52.9%). Furthermore, the percent of C in all the vine varieties was nearly equal to 50%, and this result agrees with the study of the Department of Environmental Affairs and Tourism in South Africa.

At the MC of 8.01% of pruned grapevine (dry-matter), the following portions of elements were presented; C (47.46%), H (6.81%), N (0.62%), O (44.9%), and S with 0.20% (Bilandzija *et al*. 2012). Previously, *V. vinifera* has been found to have a C content of 43.70% (Munalula and Meincken 2009). However, when comparing the obtained values with those found in the relevant literature on grapevine (Suárez-García *et al*. 2002), one can notice that in most measurements, the results from this study did not significantly differ from the literature, *i.e*., the C content (47.46%). It should be noted that the H content of the seven vine varieties was lower than hardwoods (6.4%) and softwoods (6.3%) (Table 3). The N content of *V. vinifera* ranged between 0.78 and 1.05% and represented values much higher than hardwoods (0.40%) or softwood (0.10%). The values of S content ranged from 0.009% for Kamaly to 0.269 for Black Monica. The contents of O for vine prunings were much higher than those observed in softwood and hardwood.

The relatively higher contents of N and S of the studied vine prunings in comparison to hardwoods and softwoods suggest that it might impact the environment when burned as firewood. Burning of vine prunings may increase the expected environmental problems by increasing the emitted toxic oxides to the environment, *i.e.* NO_x and SO_2, which could be contributing to acid rain as well as air and soil pollution, in addition to their negative effects on human health and other living organisms (Ismaila *et al*. 2013). However, no problems concerning N and S oxides emissions were expected if the vine prunings would be used as an alternative source to fossil fuels, *i.e*. hard coal and brown coal, due to the fact that the contents of N and S of vine prunings are very low compared to fossil fuels (Barz *et al*. 2008).

Ash content showed a highly significant effect on HV with a negative coefficient (r=-0.87). Ash is considered an undesirable material in most industrial situations. The increase of biomass utilization as a fuel may cause an ash disposal problems because it will accumulate in furnaces. Ash content of vine prunings ranged from 2.87% for Red Globe to 4.12% for Kamaly (Table 3).

It is known that the ash content of wood is less than 1%, but most wood species grown in Saudi Arabia have higher ash content above 2% (Nasser and Al-Mefarrej 2009; Al-Mefarrej *et al.* 2011; Abdel-Aal *et al.* 2011;Al-Mefarrej 2013). It should be noted that the ash content of vine was higher than hardwoods (0.9%) and softwoods (1.0%), which makes them less desirable as a fuel source because a considerable part of the volume cannot be converted into energy (Munalula and Meincken 2009). *V. vinifera* has been found to have an ash content of 0.34% (Munalula and Meincken 2009), and in another study, grapevine was found to have an ash content of 2.12% (Bilandzija *et al*. 2012). The high ash content in vine prunings might be attributed to growth conditions in Saudi Arabia where the trees grow naturally in an arid region compared to the same species growing in moist regions outside the kingdom.

Table 3. Ultimate Analysis of the Vine Pruning Comparing To Woody Plants

Vine Varieties	Content of elemental component (%)					Ash content (%)
	Carbon	Hydrogen	Nitrogen	Sulfur	Oxygen	
Soltany	46.64f	5.55bc	0.91c	0.072d	47.02a	3.83b
Halwany	47.99c	5.58b	0.91c	0.201b	45.22d	3.64c
Flame seedless	48.20b	5.58b	0.88d	0.099d	45.22d	3.20e
Kamaly	46.42f	5.45d	0.78f	0.009e	47.02a	4.12a
Red Globe	48.40a	5.68a	0.86e	0.143c	45.10d	2.87e
Thompson seedless	47.41d	5.57bc	0.99b	0.199b	45.83c	3.54d
Black Monica	46.89e	5.50cd	1.05a	0.269a	46.34b	3.86b
Correlation with HV[1]	0.96^{**}	0.92^{**}	0.12^{ns}	0.34^{ns}	-0.92^{**}	-0.93^{**}
Hardwood[2]	50.8	6.4	0.40	-	41.8	0.90
Softwood[2]	52.9	6.3	0.10	-	39.7	1.00

Means with the same letters in column are not significantly differences according to LSD test.
1: Correlation coefficient, ns: not significant and ** highly significant at 0.01 level of probability. HV is heating value on dry weight basis.
2: Data from Friedl *et al.* (2005).

Heating Value of Vine Prunings

The heating values from different vine varieties at dry weight, dry ash-free, and as received determined for the seven vine varieties are displayed in Table 4. The heating value of the seven vine varieties evaluated ranged from 18.46 to 19.19 MJ/kg (dry weight), from 19.22 to 19.75 MJ/kg (dry ash-free), and from 6.46 to 10.68 MJ/kg (as received). As expected, a higher wood density, *i.e*. for Red Globe and Halwany, related directly to a higher heating value. Furthermore, the biomass to ash ratio ranged from 20.30 to 45.92 and the FVI values ranged from 225 to 508. The lower values of biomass/ash ratio resulted from increasing the ash content of the vine prunings. Previously, it was reported that the vineyard pruning were the best fuels tested, showing comparable emission values to wood combustion, which was different from other agriculture wastes studied (Carvalho *et al.* 2013).

The results in Table 4 show that Red Globe had a higher heating value and wood density with comparatively low ash content and thus had the highest FVI (508) followed by Halwany (418) and Soltany (358); thus Red Globe appeared to have promising fuelwood properties. In the studies of Bhatt and Todaria (1990, 1992), the species were described as being suited as firewood as they contain high density wood, low ash and moisture fractions, high biomass to ash ratio, and low nitrogen percentage. Furthermore, Bilandzija *et al.* (2012) reported that the volatile matter with 73.25±8.63% and lower heating value with 17.05±2.06 MJ/kg was found in the pruned grapevine (dry-matter).

The vine prunings from the seven varieties were found to have heating values greater than some well-known biomass fuels reported in the literature, such as corncob, 17.0 MJ/kg (Demirbas 2003), tobacco stems, 17.77 MJ/kg (Pesevski *et al.* 2010), and close to the heating value of common reed, 18.92 MJ/kg (Komulainen *et al.* 2008) and *C. procera*, 19.46 MJ/kg (Hindi 2013). However, compared to other biomass fuels, the relative high heating value (18.74-19.19 MJ/kg) indicates that the vine prunings can be considered to be a promising energy source.

In general, the prunings of vine have the lowest FVI values compared with the published values in the literature on different wood species, and this can be attributed to the highest values of ash content of vine (2.87 to 4.12%). Kataki and Konwer (2001) reported that the FVI ranged from 369 for *Litsea polyantha* to 2089 for *Acacia nilotica*, where ash content ranged from 3.56 to 0.90%, respectively. This means that ash content is the most important of the variables adversely affecting on the FVI values.

Table 4. Heating Values from Different Vine Varieties at Dry Weight, Dry Ash-Free and as Received

Vine Varieties	Heating value (MJ/kg)			Biomass/ash ratio	FVI
	HHV[1]	Dry ash-free (daf)[2]	As received (ar)[3]		
Soltany	18.76ab	19.48	8.23	23.39d	358
Halwany	19.01a	19.70	6.46	23.84d	418
Flame seedless	19.14a	19.75	9.73	31.99b	347
Kamaly	18.46b	19.22	10.68	20.30e	341
Red Globe	19.19a	19.74	6.85	45.92a	508
Thompson seedless	18.94a	19.61	9.42	26.36c	225
Black Monica	18.74ab	19.46	9.47	24.29d	262

1: HHV = higher heating value dry wt basis, 2: dry ash-free fuel = HHV (1+ash/100), 3: fuel as received = lower heating value= dry weight (1-MC/100), FVI is fuelwood value index according to Bhatt and Todaria (1992), Means with the same letters in the same column are not significantly different according to LSD test at 0.05 level of probability.

Figure 2 shows the correlation between the measured heating values and carbon content, hydrogen content, and ash content from the seven vine varieties.

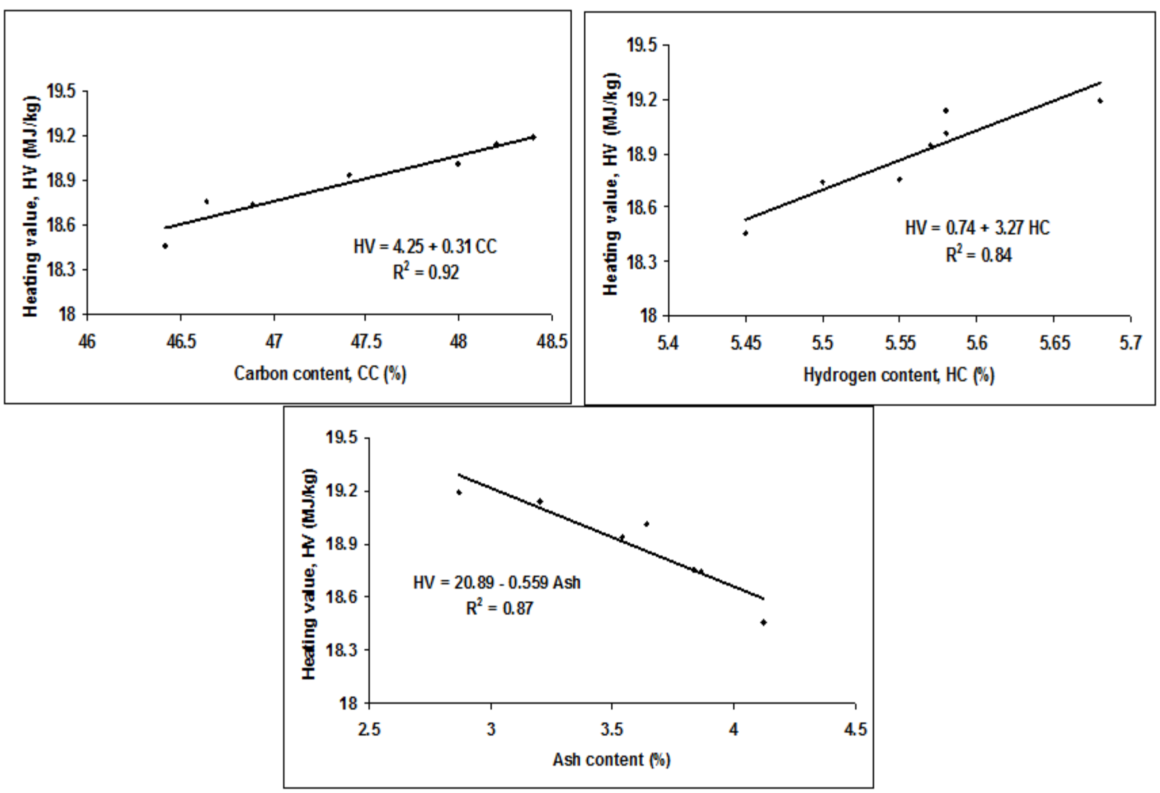

Fig. 2. Correlations between the heating values of vine prunings and its carbon, hydrogen, and ash content

The test for the correlation between the elemental composition and heating value (Table 3 and Fig. 2) showed that there were highly significant positive correlations ($P<0.01$) between the HV and carbon content ($r=0.96$) and hydrogen content ($r=0.92$). Ash content showed a highly significant effect on HV by a negative coefficient ($r=-0.93$). However, the correlation was not significant ($P>0.05$) between HV and nitrogen content ($r=0.12$) and sulfur content ($r=0.34$). By contrast, the relationship between the HV and the content of O in the vine varieties was highly significant, with a negative coefficient ($r=-0.92$).

Previously, Friedl *et al.* (2005) reported that the following elements, C, H, N, O, and S are the major elements contributing to the heating value. Additionally, the analysis of elements is a functional way to describe biomass fuels, determining their calorific values and their expected impact on the environment (Munalula and Meincken 2009; Bilandzija *et al.* 2012).

Ranking of Vine Prunings

Results for a hypothetical rating (Munalula and Meincken 2009), using the measured data of the seven vine varieties regarding all determined properties in the present study, are shown in Table 5. In this method, the vine variety Red Globe showed a preferable order (1.5) followed by the variety Flame seedless (2.7) and Halwany (3.5), while the variety Black Monica showed the poorest rating (5.8).

On the availability of high quantities, the overall rating suggests that the vine variety Red Globe and Flame seedless showed suggested parameters, and they could be more suitable for energy production in Saudi Arabia compared to the other prunings vine varieties. Moreover, further studies are needed before using the vine prunings under large scale production.

Table 5. Rating of the Seven Vine Varieties Regarding All Determined Properties

Property	Vine Varieties						
	Red Globe	Flame seedless	Halwany	Thompson seedless	Soltany	Kamaly	Black Monica
Heating value	1	2	3	4	5	7	6
Wood density	2	5	1	4	3	2	6
Ash content	1	2	4	3	5	7	6
Biomass/ash ratio	1	2	5	3	6	7	4
C content	1	2	3	4	6	7	5
N content	2	3	4	5	4	1	6
S content	4	3	6	5	2	1	7
Benzene-ethanol content	1	2	4	3	5	7	6
Lignin content	1	2	3	4	5	7	6
Fuel value index (FVI)	1	4	2	7	3	5	6
Rating value*	1.5	2.7	3.5	4.2	4.4	5.1	5.8

* According to Munalula and Meincken (2009).

CONCLUSIONS

1. *V. vinifera* was found to have medium cellulose (36.77 to 39.71%) and high lignin (26.68 to 30.18%) contents in comparison to softwood and hardwood.
2. Ash content of vine prunings ranged from 2.87% to 4.12%, making them less desirable as a fuel source.
3. The correlation was highly positive significant between the heating value and each of benzene-ethanol extractives content (r=0.74) and lignin content (r=0.94) but was highly negative significant with ash content (r=-0.93).
4. The correlations between the heating values and other chemical constituents were not significant.
5. The nitrogen content of *V. vinifera* ranged between 0.78 to 1.05%, and the sulfur content ranged from 0.009 to 0.269%, which was much higher than either hardwoods or softwood.
6. It is expected that burning of vine prunings may increase environmental problems by increasing the emitted toxic oxides to the environment, *i.e.* NO_x and SO_2.
7. The relative high heating value (18.74 to 19.19 MJ/kg) indicates that the vine prunings are promising as an energy source. They exhibited heating values greater than some well-known biomass fuels reported in the literature.
8. The prunings of vine exhibited the lowest FVI values (225 to 508) compared with the published values in the literature for different wood species.
9. In accordance to fuel characteristics, the vine prunings could be suitable as a source for energy production. The vine variety Red Globe and Flame seedless showed preferable characteristics and they could be more suitable for energy production than other studied vine varieties in Saudi Arabia.

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