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RESEARCH ARTICLE

ENERGY STUDIES OF SOME CASHEW NUT BY-PRODUCTS IN KENYA

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Abstract

From its humble native origin in the Amazon Basin, cashew tree (*Anacardium occidentale*) was introduced to the East African coast and subsequently Indian subcontinent by the Portuguese explorers in the 16^{th} and 17^{th} centuries. Today cashew tree is grown as a cash crop in many countries around the world with equatorial and tropical climate.

Despite its long history on the East African coast, the cashew tree was only established as a commercial crop along the Kenyan Coast around 193o's. Although Kenya has the potential to produce 200,000 MT of cashew nut per year which would produce about 45,000MT of CNSL assuming that all the nuts are processed locally with the attendant extraction of CNSL, yet the actual annual production fluctuates between 10,000 to 15,000 MT on the average with no known local extraction of CNSL. CNSL is a versatile material with many applications in the manufacture of friction dust for brake linings and clutch facing, different types of coatings, adhesives and pesticides among many others.

In recent years, due to escalating cost of conventional fuels, a number of cashew nut processors and other industries have turned to the use of cashew nut shell as fuel. Burning of cashew nut shell which holds about 30% of CNSL of its total weight in furnaces, produces excessive heavy dark smoke with particulate matter which pollutes the atmosphere in very profound manner.

The goal of this research is to point to an alternative more environmentally friendly method of disposing cashew nut shell which has also got additional economic benefits.

Specific amount of cashew nut shell was milled and CNSL was extracted from the sample by means of n-Hexane as solvent. CNSL and its isolates, cardanol and cardol were evaluated for some of their characteristics with a view to determining their quality and hence suitability as industrial raw materials. These materials plus CN shell (both spent and unextracted) were evaluated for their energy content and compared with that of some of the conventional fuels. Characteristics of CNSL, cardanol and cardol compared favorably well with data from literature.

From the energy studies, it was established that Cashew nut byproducts (CNSL, its isolates and spent CN Shell) compares quite favorably well with conventional fuels in terms of energy content. While liquid byproducts (CNSL, Cardanol and Cardol) were more superior than all liquid and solid conventional fuels cited, spent CN shell was more superior to a number of liquid fuels eg ethanol and methanol and fire wood in terms of energy content. It is this material which is advocated to be used by cashew nut processors and other industries as fuel instead of using shell laden with CNSL as this would reduce environmental pollution. This material is not only a cleaner fuel but also has low ash and is renewable. If extracted, CNSL may be sold as a commercial commodity or turned into a number of products with a higher value.

Abbreviations:
CNSL - cashew nut shell Liquid
FAO - Food and Agricultural Organization
JKUAT - Jomo Kenyatta University of Agriculture and Technology
RPE - Research Production and Extension

Introduction

From its humble native origin in the Amazon Basin, cashew tree was introduced to the East African coast and subsequently Indian subcontinent by the Portuguese explorers in the 16th and 17th centuries. Today cashew tree is grown as a cash crop along the coasts of many countries with equatorial and tropical climate around the world.
Some of the major producers of cashew nuts include Brazil, India, Vietnam, Nigeria, and Tanzania among others.
In 2008 global production of cashew nuts according to the FAO Report was around 3.2 m MT
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The Cashew industry in Kenya.

Despite its long history on the East African coast, the cashew tree was only established as a commercial crop along the Kenyan Coast around 1930's and commercial processing started in 1939.The two main methods of processing the nuts are the oil bath and the steaming methods. The first method involves passing moistened nuts though an oil bath in which the largely heated and expanded moisture in the shell disrupt the structure of the shell and cause some of the oil (CNSL) to be spilt into the oil bath. Consequently emptying of the oil above a certain set depth has to be done intermittently. Although some CNSL is recovered with this method, the bulk of it is normally left in the shell. On the other hand the steaming method involves steaming the moistened nuts with high pressure steam. This produces the same effect as the oil bath method that is, of weakening the shell by making it brittle and easier to crack to remove the kernel. This is the main method applied by most cashew nut processors in Kenya whereby no CNSL is recovered.
Although the tree is the oldest cash crop in Kenya where the country has the potential to produce 200,000 MT of cashew nut per year which would produce about 45,000MT of CNSL assuming that all the nuts are processed locally with the attendant extraction of CNSL, yet the actual annual production fluctuates between 10,000 to 15,000 MT. on the average with no known local extraction of CNSL. CNSL is a versatile material with many applications in the manufacture of friction dust for brake linings and clutch facing, different types of coatings, adhesives, and pesticides among many others. For considerable period of time, Interest has been expressed to exploit cashew nut by-products as source of fuel. Bio-oil from pyrolysis of cashew nut shell—a near fuel
Piyali and Ganesh, (undated) have reported that CNS oil as having calorific value as high as 40 KJ/g and as low as ash content of 0.01 %. Elsewhere ash content of CN shell has been reported as 3.34% (Senger et al, 2011). The latter value appears more realistic compared to other similar biological materials. Cashew nut shell cake has been reported as a suitable fuel in cement , tiles and brick manufacture. (http://www.sridevigroup.com/#).
In recent years in Kenya, due to escalating cost of conventional fuels, a number of cashew nut processors have turned to the use of cashew nut. Figure 1 illustrates the various molecules present in a sample of CNSL. Technically there could be not less than 16 chemically different types of molecules in the sample.
Different authors have reported varying composition of CNSL. This may be explained by the varying climatic and geographic conditions in which the nut is grown. (Kumar, et al 2002) for example has reported composition of a typical solvent extracted CNSL as containing anacardic acid (60-65%), cardol (15-20%), polymeric material (10%) and traces of 2-methylcardol, while technical CNSL consists of cardanol (60-65%), cardol (15-20%), polymeric material (10%) and traces of 2-methyl cardol. On the other hand (Anon 2006) has reported the composition of natural (cold extracted) as consisting of: 70% anacardic acid, 8% cardol, and 5% cardanol, with the remainder being made up of other phenols and less polar substances.
The current practice with cashew nut processors is to burn cashew shell as fuel. Other industries have followed suit and have become buyers of cashew nut shell.
Burning of cashew nut shell which holds about 30% of CNSL of its total weight in furnaces produces excessive heavy dark smoke with particulate matter. This is expected considering the high concentration of carbon in the various CNSL Pollution to the environment derived from this practice is quite profound. Some of the pollutants expected from burning cashew shells include mainly, Carbon particles, CO, NO_x and hydrocarbon residues. In the presence of sunlight, this mixture may produce ozone and chemical smog as secondary pollutants. These pollutants pose health risk to human, other animals and plants.

It is in this background that this project was carried out with the aim of pointing to an alternate method of disposal of cashew nut shells which is not only environmentally friendly but with expected additional economic benefits to the stakeholders in the cashew industry.

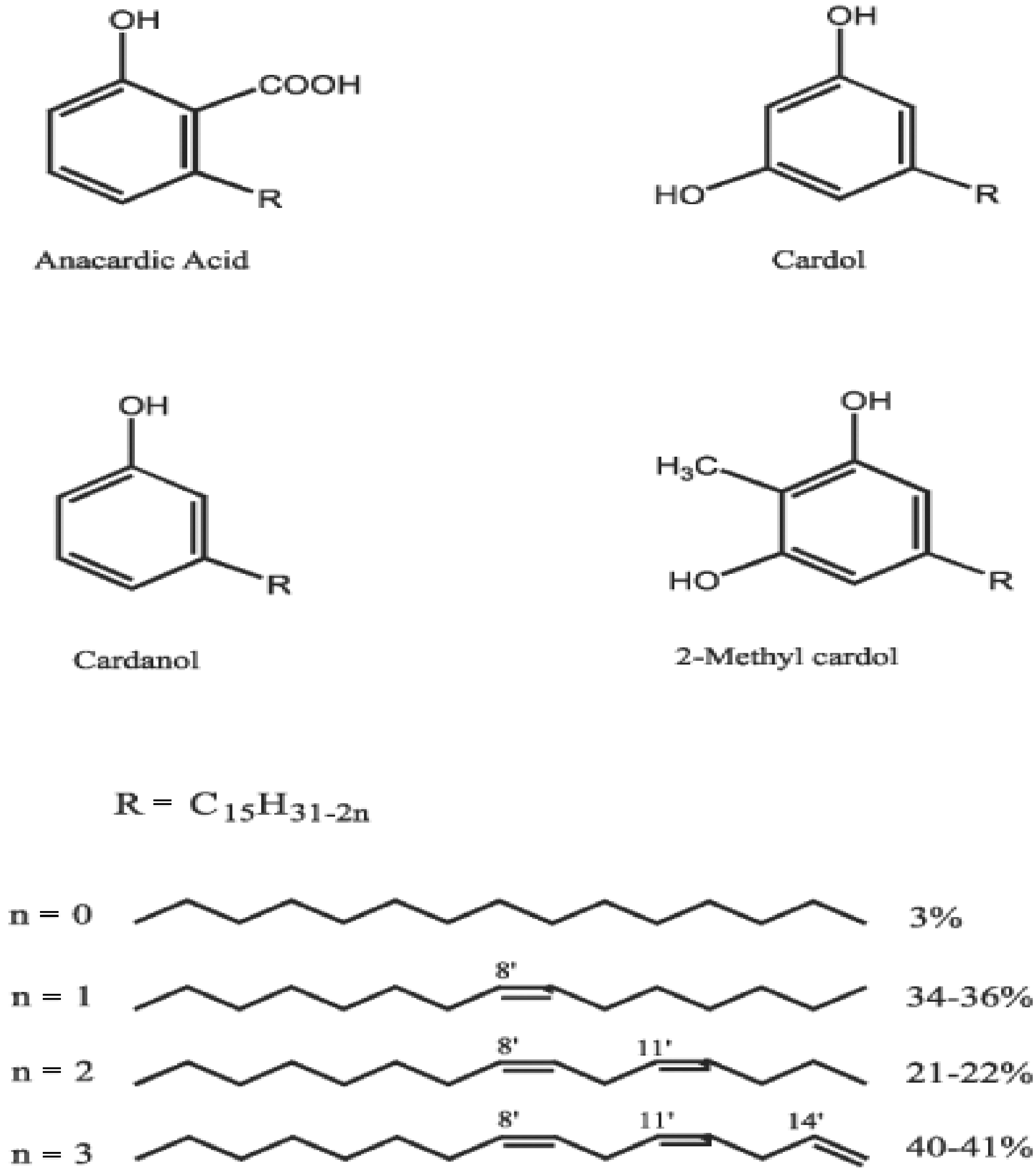


Figure 1: Chemical composition of CNSL (Rodriguez *et al*, 2006)

Material and Methods

Cashew nut shell was obtained from Kenya Nut Company in Thika, Kiambu County. It was then milled using screw press mill at the Mechanical Engineering Workshops at JKUAT. CNSL was extracted using n-Hexane as solvent. The clear miscella obtained after filtration was evaporated using a rotor evaporator and the solvent was recovered for re-use. The residual or ‘spent’ shell was reserved for energy studies.

The raw CNSL was decarboxylated by heating in an Erlenmeyer flask at 135-140^{O}C for one hour or until all effervescence ceased.

Characterization of CNSL and its isolates

Moisture content of CNSL and its isolates was done using Dean and Stark apparatus. Association of Official Analytical Chemists (AOAC, 1990) method was adopted for this.

Viscosity was determined using a Thermominder water bath at 40^{o}C and a capillary viscometer.

A pH meter of Combo Gro'check make from Hanna instruments, model no H1991404 was calibrated and used to determine the pH of the samples. Specific Gravity was done using a pycnometer at 25^{o}C. Iodine value was determined according to the method used by (Strong and Koch), 1974).

FTIR spectra of the samples were obtained using Shimadzu model 8400 spectrometer. A small amount of the sample was smeared on a KBr liquid cell and run in the FTIR machine and the various peaks recorded.

Calorific values were determined by the use of an Oxygen bomb calorimeter, model 1KQ-kalorimeterwith an adiabatic system where an electrolyte is used to regulate the heat of the system. Calorific values of solid samples (CNS cake and the spent (exhausted) cake) were determined by the use of capsule whereas that of the liquid samples were determined in the normal way (without use of the capsule).

Result and Discussion

Decarboxylation of raw CNSL involves loss of a carbon dioxide molecule from anacardic acid. During this step all anacardic acid in the oil was effectively converted to cardanol. Isolation of cardanol and cardol from decarboxylated CNSL was done according to an adopted method from those reported by Paramashivapa et al, (2002) Kumar, et al, (2002) and Risfaheri, et al, (2009)

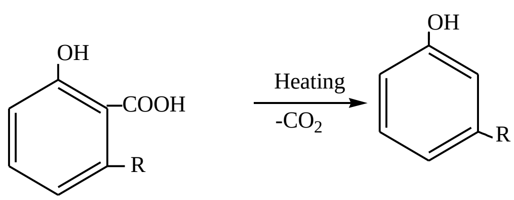


Figure 2. Decarboxylation of raw CNSL.

Table 1 gives a comparison of characteristics of the various samples.

Table 1. Characteristics of CNSL and its isolates.

Sample	Raw CNSL	Decarboxylated CNSL	Cardanol	cardol
Moisture content (Wt %)	0.673	0.422	0.810	0.818
Viscosity (cps)	32.419	28.426	24.324	26.424
pH	5.83	6.01	3.43	4.25
Specific gravity	0.995	0.939	0.985	0.953
Iodine Value	244.70	243.54	244.21	243.69

Brazilian and Indian standard specifications (Risfaheri, 2009). among others from suppliers (Tradeasia and Sanoor Cashew) were used in comparing the characteristics of CNSL and its isolates.

Moisture content of the samples of less <1% was within the specifications.

Moisture in CNSL and its isolates may explained from the fact that nuts are moistened before roasting and then during isolation of cardanol and cardol, aqueous solutions were introduced.

Viscosity values for the samples deviated significantly from standard Indian and Brazilian Standard specifications values perhaps due to the higher temperature used in determination (in our case 40^{0}C was used). Specific gravity, iodine values and pH of the samples were generally comparable except the pH for cardanol, which was rather low (3.43). This could be due to the introduction of HCl during the washing step which was not thoroughly flashed off with wash water.

FTIR SPECTRA Figures 3 to 6 depict FTIR spectra of raw CNSL, decarboxylated CNSL, cardanol and Cardol.

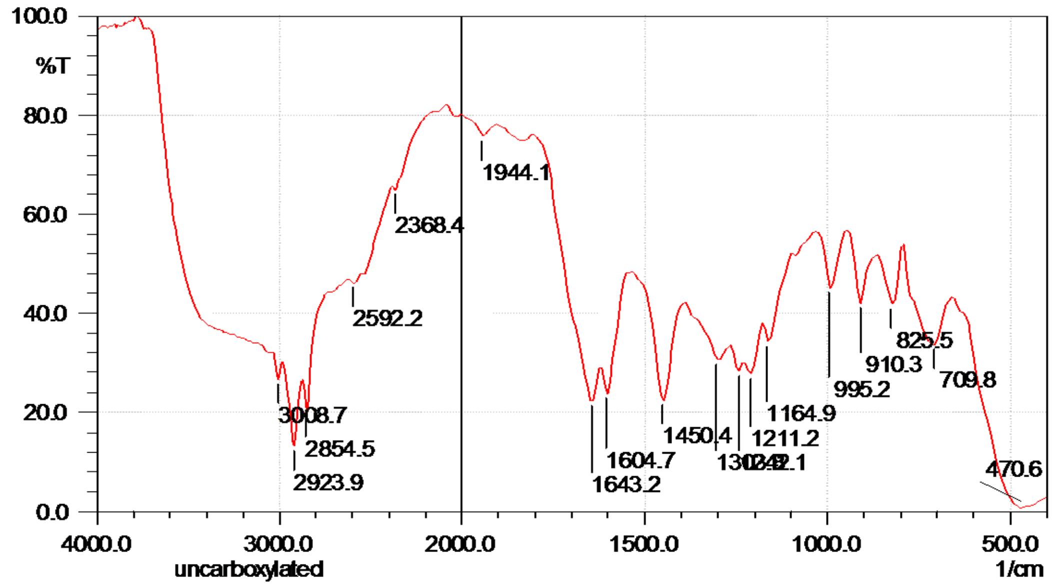


Figure 3: FTIR spectrum of Raw CNSL

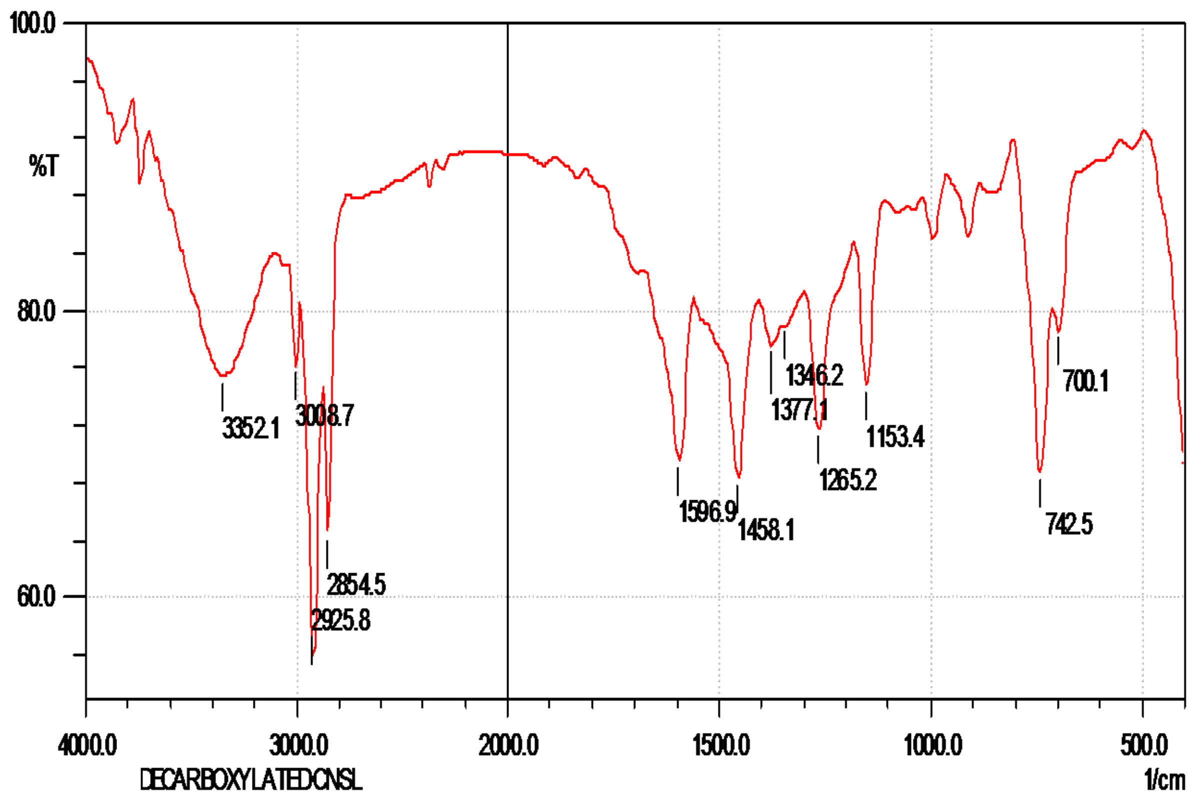


Figure 4: FTIR Spectrum of Decarboxylated CNSL.

Figure 5: FTIR spectrum of cardanol

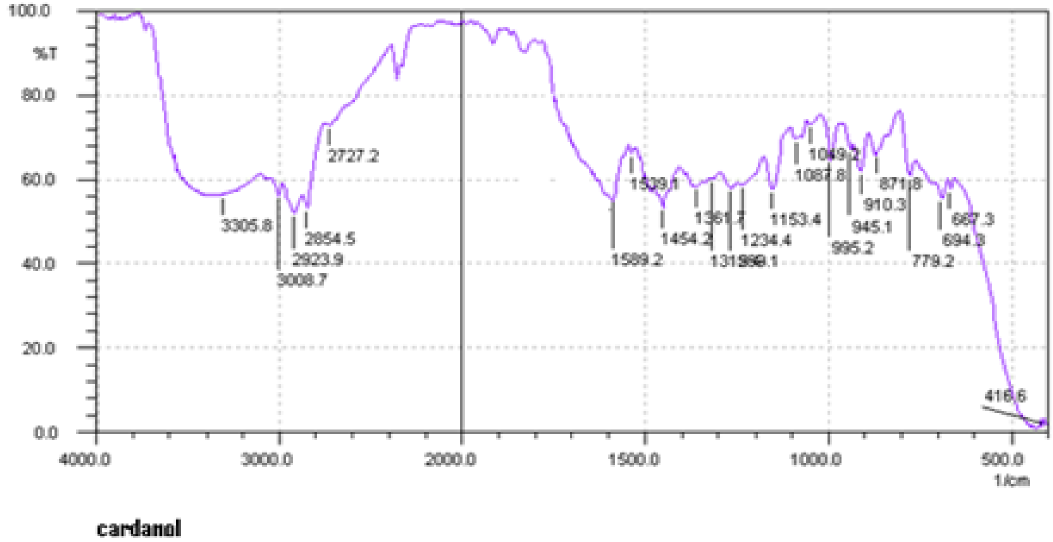
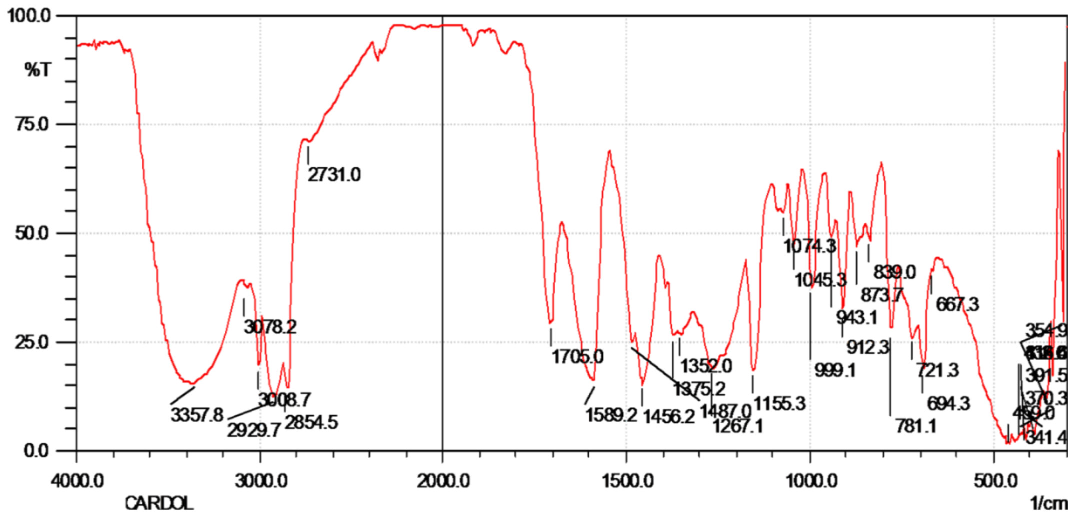


Figure 6: FTIR spectrum of cardol



In agreement with the structures of CNSL fractions presented in Figure 1, all the spectra showed absorption in the region 3305-3363cm^{-1}, 3008.7cm^{-1}, 2923-2929cm^{-1}and 2354.5 cm^{-1} , representing O-H stretch, C-H stretch for aromatic ring and C-H stretch for aliphatic group respectively. Further absorption shown by all samples include that in the region 1587.2 to 1604 cm^{-1} representing C=C aromatic stretch. Absorption around 2545-2592 cm^{1} which was unique to raw CNSL represents –C=O stretch for carboxylic group attached to the aromatic ring.
Calorific values of CNSL, its isolates and the CN shell are presented on Table 2. while those of conventional liquid and solid fuels are presented on Table 3.

Table 2. Calorific values of CNSL, its isolates and the milled CN shell.

Sample	CNSL (raw)	Cardanol	Cardol	Milled CN shell	Exhausted CN shell
Calorific value (KJ/g)	46.27	53.55	51.79	34.15	29.90

Table 3. Calorific values of some of the conventional fuels.

Fuel	Calorific value (KJ/g)
Ethanol	30.0
Methanol	23
General purpose coal (5-10% water)	32 - 42
Steam coal (1% water)	36
Wood (16% water)	16
Diesel fuel	46
Petrol	44.8 – 46.9

Calorific values of cashew nut byproducts (CNSL, its isolates and spent CN Shell) compares quite favorably well with conventional fuels in terms of energy content. Liquid byproducts (CNSL, Cardanol and Cardol) were more superior than all liquid and solid conventional fuels. The higher energy content of CN byproducts may be explained on account of the much higher carbon content in CN byproducts (an CNSL molecule has 21 Carbon atoms and about 28 H- atoms on average).

Spent CN shell is more superior to a number of liquid fuels eg ethanol and methanol and fire wood in terms of energy content. It is this material which is advocated to be used by cashew nut processors and other industries as fuel instead of using shell laden with CNSL.

If extracted, CNSL may be sold as a commercial commodity or turned into a number of products with a higher value addition.

Conclusion

The current practice among cashew nut processors and other industries of burning CN shell as fuel is objectionable, due to its profound pollution of the atmosphere. A better alternative disposal method for CN shell, is to extract CNSL preferably by solvent method, thus obtaining a useful industrial commodity and a clean fuel. Spent CN shell is not only superior to a number of conventional fuels such as firewood, but is a renewable material with low ash content.

Acknowledgements

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