

AGRO-WASTE AS SOURCE OF FINE AND INDUSTRIAL CHEMICALS: SYNTHESIS OF 2-FORMYL-6-HYDROXYBENZOIC ACID AND 4-METHOXYISOBENZOFURAN-1,3-DIONE FROM CASHEW NUT SHELL LIQUID

Lydia Kisula,¹ Stephen J.M. Mdachi,² Charles de Koning³ and Quintino A. Mgani^{2*}

¹Tanzania Industrial Research Developments Organization,
P.O. Box 23235 Dar es Salaam, Tanzania,

²Chemistry Department, University of Dar es Salaam,
P.O. Box 35061, Dar es Salaam, Tanzania,

³School of Chemistry, University of Witwatersrand,
Private Bag 3, Wits, 2050, Republic of South Africa

* Correspondence address: qmgani@udsm.ac.tz

ABSTRACT

This paper reports on the synthesis of 2-formyl-6-hydroxybenzoic acid (**8**) and 4-methoxyisobenzofuran-1,3-dione (**10**) from a renewable natural material Cashew Nut Shell Liquid (CNSL) achieved in five and seven steps, respectively. Anacardic acid was isolated from CNSL, dimethoxylated into (E)-methyl 2-methoxy-6-(pentadec-8-enyl)benzoate which was subsequently hydrogenated into methyl 2-methoxy-6-pentadecylbenzoate. Benzylic bromination of the methoxyester, and dehydrobromination afforded (E)-methyl 2-methoxy-6-(pentadec-1-enyl)benzoate which upon ozonolysis gave methyl 2-formyl-6-methoxybenzoate. Oxidation and dehydration of **8** formed methoxyphthalic anhydride (**10**). The work reported in this paper has further demonstrated the resourcefulness of cashew nut shell liquid as a renewable natural resource for synthesis of fine and industrial chemicals.

Keywords: *Anacardium occidentale*, Cashew Nut Shell Liquid, Anacardic acid, 2-formyl-6-methoxybenzoate, methoxyphthalic anhydride

INTRODUCTION

The depletion of fossil fuels as sources of fine chemicals for various applications calls for search for alternative renewable sources. Nature is abounding with materials which when appropriately manipulated can serve as renewable supplies of fine chemicals. One such material is Cashew Nut Shell Liquid (CNSL) from the cashew plant *Anacardium occidentale* which is grown along the coast of Tanzania for its kernels, cashew nuts. CNSL is rich in phenolic compounds with unsaturated C₁₅ side

chain *meta* substituents (Akinhanmi and Atasié 2008). Both the alkene, phenolic and carboxylic acid functional groups present in these natural lipids renders components of CNSL amenable to transformations into a variety of materials and fine chemicals (dos Santos and de Magalhaes 1999; Rodrigues *et al.* 2006; Yadavi and Srivastava 2008; Logrado *et al.* 2010; Vasapollo *et al.* 2011; Vempati *et al.* 2011; Reddy *et al.* 2012; Wisastra *et al.* 2012; Gandhi *et al.* 2014). As a continuation of efforts to add value to the abundantly available agro-waste

cashew nut shells (CNS) from the cashew nut industry in Tanzania (Mmongoyo *et al.* 2012; Mkungu *et al.* 2013; Mgaya *et al.* 2015, 2016), this paper reports on the successful conversion of anacardic acid (**1**) into fine chemicals methyl 2-formyl-6-methoxybenzoate (**8**) and 4-methoxyisobenzofuran-1,3-dione (**10**). Compound **10** and its precursor aldehyde **8** are versatile starting fine chemicals for a number of transformations in natural product synthesis (Dhananjeyan *et al.* 2005; Singh and Geentanjali 2005; Naysmith and Brimble 2013, Schunemann *et al.* 2014). Hydrolysis of the ester group and demethylation of the ether group is expected to give 2-formyl-6-hydroxybenzoic acid, an equally resourceful synthetic intermediate.

MATERIALS AND METHODS

Material, Reagents, Instruments and General Procedures

Dry cashew nut shells were collected from Southern Jumbo, a small scale cashew processing factory in Dar es Salaam. All reagents and chemicals were purchased from Sigma Aldrich, South-Africa. Solvents were distilled prior to use. All reactions were carried out in oven-dried glassware. Organic layers obtained following workup of reaction mixtures were dried over anhydrous MgSO₄. Column chromatographic separations were performed by using EM type 60 silica gel (230-400 mesh). Analytical Thin Layer Chromatography (TLC) was performed on Merck pre-coated silica gel (60F₂₅₄/0.2 mm) plates and spots were visualized using UV light at 254 nm and/or anisaldehyde spray reagents. A Bruker Optic GmbH 2011 FT-IR spectrophotometer was used for IR data acquisition. ¹H and ¹³C NMR spectra were recorded in deuterated chloroform (CDCl₃) at 300/500 MHz on a Bruker A.G. spectrometer and chemical shifts are reported in parts per million (δ) downfield from

tetramethylsilane (Me₄Si) as internal standard. Coupling constants were reported as *J* (Hz) and multiplicities with abbreviations d, doublet; dd, double doublet; t, triplet; br, broad and m, multiplet.

Isolation of Anacardic Acid

Cashew nut shells (500 g) were soaked in 1000 mL of 99% ethanol for 48 hours and then filtered to obtain 850 mL of cashew nut shell liquid extract. To the 850 mL extract, a total of 20.00 g of calcium hydroxide was added portion-wise and stirred for 3 hours while the temperature was maintained at 50 °C. The calcium anacardate (40.34 g) precipitated was collected by filtering under vacuum. Calcium anacardate (20.00 g), suspended in 80 mL of distilled water, was mixed with 13 mL of 11 M HCl and the resulting mixture was stirred for 3 hours and then extracted with ethyl acetate (2 × 100 mL). The combined ethyl acetate extract was washed with distilled water (2 × 50 mL) and dried over MgSO₄. Filtration of the drying agent followed by evaporation of the solvent gave 11.00 g (58% yields) of the crude anacardic acid (**3**).

Preparation of methyl 2-methoxy-6-(pentadec-8-en-1-yl)benzoate (**4***)

In a 250 mL round bottomed flask containing compound **5** (11.00 g, 0.030 mol), dissolved in 200 mL acetone, was added K₂CO₃ (20.00 g, 0.150 mol) followed by portion-wise addition of dimethyl sulphate (18.90 g, 0.150 mol). The reaction mixture was refluxed in an oil bath for 24 hours under a nitrogen atmosphere and then cooled to room temperature. After the evaporation of acetone, the reaction mixture was extracted with ethyl acetate (2 × 100 mL) and the combined organic extract washed with water (2 × 50 mL). The organic layer was dried over MgSO₄, filtered and the solvent evaporated in the rotary evaporator and then under high

vacuum. The crude product was then purified by column chromatography over silica gel using a mixture of hexane/ethyl acetate (95:5) to afford compound **4*** (Fig.1) as a pale yellow liquid (6.00 g, 54%). ^1H NMR (300 MHz, CDCl_3): $\delta_{\text{H}} = 0.86$ (t, 3H), 1.3 (m, 16H), 1.57 (m, 2H), 2.00 (m, 4H), 2.51 (t, $J = 8.0$ Hz, 2H), 3.8 (s, 3H), 3.9 (s, 3H), 5.32 (m, 2H), 6.73 (d, $J = 8.4$ Hz, 1H), 6.83 (d, $J = 7.5$ Hz, 1H) and 7.20 (t, $J = 7.8$ Hz, 1H). FTIR (Film): 722.86 cm^{-1} , 1289.73 cm^{-1} , 1307.77 cm^{-1} , 1404.06 cm^{-1} , 1524.83 cm^{-1} , 1569.86 cm^{-1} , 1584.23 cm^{-1} , 1626.54 cm^{-1} , 2852.73 cm^{-1} , 2923.83 cm^{-1} and 3479.50 cm^{-1} .

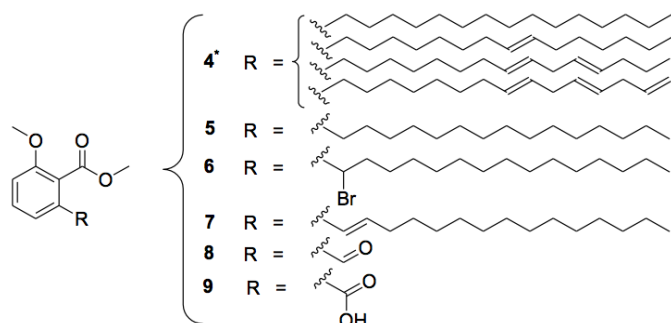


Figure 1: Some Derivatives of Anacardic Acid (**5**); * = compound **4** is named on the basis of the predominant $\Delta 8$ monoenvl substituent.

Preparation of methyl 2-methoxy-6-pentadecylbenzoate (**5**)

To a stirred solution of **4*** (6.00 g, 0.020 mol) in 200 mL methanol was added 10% palladium-on-carbon, Pd/C (0.23 g) and then hydrogen gas was passed through the solution for 12 h. The reaction mixture was filtered over a celite bed and washed with methanol (100 mL). The filtrate was concentrated under reduced pressure to afford product **5** (Fig. 13) as pale yellow liquid (5.70 g, 95%). ^1H NMR (300 MHz, CDCl_3): $\delta_{\text{H}} = 0.88$ (t, 3H), 1.25 (m, 25H), 1.55 (m, 2H), 2.53 (t, $J = 7.8$ Hz, 2H), 3.81 (s, 3H),

3.90 (s, 3H), 6.76 (d, $J = 8.4$ Hz, 1H), 6.83 (d, $J = 7.5$ Hz, 1H) and 7.26 (t, $J = 8.1$ Hz, 1H).

Preparation of methyl 2-(1-bromopentadecyl)-6-methoxybenzoate (**6**)

In an oven dried round bottomed flask containing compound **5** (5.70 g, 0.020 mol) in 100 mL of CCl_4 were added AIBN (0.99 g, 0.010 mol) and NBS (2.90 g, 0.020 mol). The mixture was refluxed in an oil bath for 24 hours and then cooled to room temperature. The reaction mixture was extracted with CHCl_3 (3×100 mL) and the combined organic extract was washed with water (3×50 mL) and dried over MgSO_4 . The drying agent was filtered off and the solvent evaporated in the rotary evaporator and under high vacuum to give a crude product, which was purified by column chromatography over silica gel using hexane/ethyl acetate mixture (95:5) to yield a yellowish liquid (4.56 g, 84%) of bromide **6**. ^1H NMR (300 MHz, CDCl_3): $\delta_{\text{H}} = 0.88$ (t, $J = 6.5$ Hz, 3H), 1.25 (m, 22H), 1.57 (m, 2H), 2.14 (m, 2H), 3.83 (s, 3H), 3.94 (s, 3H), 4.91 (t, $J = 7.4$ Hz, 1H), 6.85 (d, $J = 8.1$ Hz, 1H), 7.26 (d, $J = 7.8$ Hz, 1H), and 7.38 (t, $J = 8.1$ Hz, 1H).

Preparation methyl 2-methoxy-6-(pentadec-1-en-1-yl)benzoate (**7**)

An oven dried 250 mL round bottomed flask was charged with compound **6** (4.50 g, 0.010 mol) in 150 mL of dry toluene and DBU (2.30 g, 0.015 mol) under nitrogen atmosphere. The reaction mixture was heated at $80\text{ }^\circ\text{C}$ for 15 hours. The reaction mixture was cooled to room temperature, evaporated in the rotary evaporator, followed by extraction with ethyl acetate (3×100 mL). The organic phase was washed with water (3×50 mL) and dried over

MgSO₄. The drying agent was filtered off and the solvent evaporated in rotary evaporator followed by high vacuum pump to give the crude product, which was purified by column chromatography (silica gel, 90:10 hexane/EtOAc) to yield the alkene **7** (Fig. 1) as white crystals (2.28 g, 60% yield). ¹H NMR (300 MHz, CDCl₃): δ_H = 0.88 (t, 3H), 1.26 (m, 20H), 1.44 (m, 2H), 2.17 (q, 2H), 3.83 (s, 3H), 3.92 (s, 3H), 6.25 (m, 2H), 6.78 (d, 1H), 7.11 (d, 1H) and 7.27 (t, 1H),

Preparation of methyl 2-formyl-6-methoxybenzoate (**8**)

To a stirred solution of methyl 2-methoxy-6-(pentadec-1-en-1-yl)benzoate (**7**) (2.28 g, 0.006 mol) in dry CH₂Cl₂ (100 mL) was added Sudan III indicator (2 drops) while maintaining the reaction temperature at -8 °C. Ozone gas was bubbled into the reaction mixture until the color changed from pink to colorless. Argon gas was passed into the reaction mixture for 10 minutes and dimethyl sulfide (5.06 g, 0.081 mol) was then added at -78 °C. The reaction mixture was then warmed to room temperature and stirred for 1 hour. The reaction mixture was then concentrated in a rotary evaporator and the residue purified by column chromatography over silica gel (15% EtOAc/hexane) to afford 1.14 g, (63% yield) of the product **8** (Fig. 1) as a white powder. ¹H NMR (300 MHz, CDCl₃): δ_H = 3.89 (s, 3H), 3.98 (s, 3H), 7.26 (d, 1H), 7.47 (d, 1H) and 9.97 (s, 1H). ¹³C NMR (75 MHz, CDCl₃): δ_C = 52.55 (C-9), 56.28 (C-10), 116.67 (C-6), 122.49 (C-4), 123.61 (C-2), 130.84 (C-5), 134.35 (C-3), 156.27 (C-1), 167.47 (C-8) and 190.05 (C-7). FTIR (Film): 750.06 cm⁻¹, 903.16 cm⁻¹, 948.21 cm⁻¹, 1148.10 cm⁻¹, 1316.06 cm⁻¹, 1498.30 cm⁻¹, 1657.73 cm⁻¹, 1691.46 cm⁻¹, 1733.11 cm⁻¹, 2848.93 cm⁻¹, 2990.60 cm⁻¹ and 3007.65 cm⁻¹.

Preparation of 3-methoxy-2-(methoxycarbonyl)benzoic acid (**9**)

In an oven dried 50 mL round bottomed flask containing compound **8** (0.10 g, 0.520 mmol) in 10 mL *tert*-butanol/water (1:1 ratio) were added cyclohexene (0.10 g, 0.0012 mol), NaH₂PO₄ (0.10 g, 0.830 mmol) and NaClO₂ (0.07 g, 0.770 mmol). The reaction mixture was stirred for 3 hours when TLC analysis indicated no starting material. The reaction mixture was evaporated using a rotary evaporator and the residue extracted with ethyl acetate (2 × 50 mL). The combined EtOAc extract was washed with 50 mL of water and dried over MgSO₄. After filtering off the drying agent, the solvent was evaporated in rotary and in high vacuum to yield compound **9** (Fig. 1) as a needle-shaped crystalline product (0.010 g, 98% yield). ¹H NMR (300 MHz, CDCl₃): δ_H = 3.88 (s, 3H), 3.94 (s, 3H), 7.17 (d, *J* = 8.4 Hz, 1H), 7.43 (t, *J* = 8.1 Hz, 1H) and 7.70 (d, *J* = 7.8 Hz, 1H). ¹³C NMR (75 MHz, CDCl₃): δ_C = 52.72 (C-9), 55.45 (C-10), 115.45 (C-4), 122.72 (C-5), 125.45 (C-2), 128.18 (C-1), 130.01 (C-6), 156.36 (C-3), 168.18 (C-8), and 169.09 (C-7). FTIR (Film): 634.17 cm⁻¹, 1043.62 cm⁻¹, 1235.79 cm⁻¹, 1372.78 cm⁻¹, 1589.20 cm⁻¹, 1736.47 cm⁻¹, 2662.92 cm⁻¹, 2939.57 cm⁻¹, 2983.67 cm⁻¹ and 3513.54 cm⁻¹.

Preparation of 4-methoxyisobenzofuran-1,3-dione (**10**)

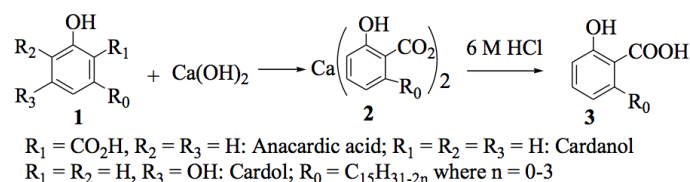
In a 50 mL round bottomed flask containing compound **9** (0.10 g, 0.470 mmol) were added thionyl chloride (6.56 g, 0.060 mol) under a nitrogen atmosphere and the mixture refluxed for 12 hours. The reaction mixture was allowed to cool to room temperature, diluted with dichloromethane (100 mL) and then washed with 50 mL of aqueous NaHCO₃ followed by dilute HCl. The organic layer obtained was dried over MgSO₄ and the drying agent filtered off. The filtrate was evaporated in the rotary

evaporator and dried under high vacuum pump to yield 0.08 g (95%) of the anhydride **10** as a needle-shaped crystalline material. ^1H NMR (300 MHz, CDCl_3): δ_{H} = 4.08 (s, 3H), 7.33 (d, J = 8.5 Hz, 1H), 7.59 (d, J = 7.5 Hz, 1H) and 7.85 (t, J = 8 Hz, 1H). ^{13}C NMR (75 MHz, CDCl_3): δ_{C} = 56.65 (C-9), 116.36 (C-2), 117.48 (C-4), 118.60 (C-6), 132.54 (C-1), 138.36 (C-5), 157.52 (C-3), 160.36 (C-7) and 162.59 (C-8).

RESULTS AND DISCUSSION

Extraction of CNSL from CNS and Isolation of Anacardic Acid (**3**)

The cashew nut shells obtained from a cashew nut processing factory in Dar es Salaam were solvent extracted with 99% ethanol for 48 hours to obtain natural cashew nut shell liquid (*n*CNSL) (Murthy *et al.* 2009). The yield of the CNSL was 27% of the weight of the dry shells which compares well with a 31% yield reported by Paramashivappa *et al.* (2001). Anacardic acid was subsequently separated from the mixture following a slight modification of Paramashivappa protocol (2001). CNSL was dissolved in 5% aqueous methanol to which calcium hydroxide was slowly added while stirring vigorously. The more acidic anacardic acid reacted with the base precipitating the acid as calcium anacardate while leaving in solution the weakly acidic phenols, cardol and cardanol (Scheme 1).



Scheme 1: Isolation of Anacardic acid from *n*CNSL

The calcium anacardate was acidified with 6 M HCl to obtain a mixture constituting monoene,

diene and triene anacardic acids in 55% yield from CNSL. The yields compare well with that in literature at 60% (Gandhi *et al.* 2012).

Transformation of anacardic acid to 4-methoxyisobenzofuran-1,3-dione (**10**)

The synthetic transformation of anacardic acid to the desired phthalic anhydride **10** commenced with the protection of the phenolic and carboxylic hydroxyl groups by methylation to yield compound **4** (Scheme 2) in 54% yield. Although Scheme 2 depicts compound **4** as having the Δ^8 -monoene C_{15} substituent, **4** is in reality a mixture in which the C_{15} side chain occurs as a pentadecyl, Δ^8 -pentadecenyl, Δ^8 -11-pentadecadienyl and Δ^8 ,11,14-pentadecatrienyl carbon chain. However, it is worth noting that the monoene (Δ^8 -pentadecenyl) side chain constitutes the predominant structure of the C_{15} substituent in all the CNSL phenols and hence the basis for formulating compound **3** and **4** as shown in Scheme 2. The Scheme summarizes the complete synthetic transformation of anacardic acid (**3**) to 4-methoxyisobenzofuran-1,3-dione (**10**).

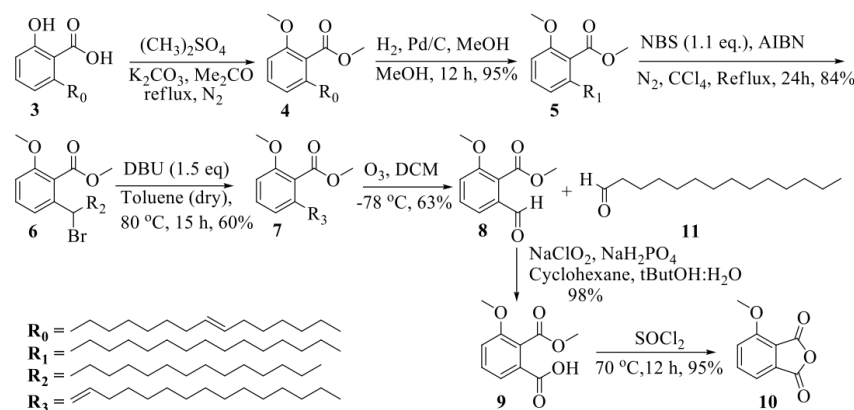
The ^1H NMR spectrum for compound **4** showed signals for the aromatic protons as a doublet at δ_{H} 6.73 (for H-3), doublet at 6.83 ppm (H-5) and triplet at 7.20 ppm (H-4). The methoxy protons (3H) appeared as a singlet at 3.80 ppm whereas the carbomethoxy protons (3H) appeared as a singlet at 3.9 ppm. The terminal methyl group (H-15') of the Δ^8 -pentadecenyl side chain appeared as a triplet integrating for three protons at δ_{H} 0.86 ppm. The methylene (CH_2) groups were observed as a multiplet at δ_{H} 1.30 ppm while the benzylic protons (H-1') appeared as a triplet at a δ_{H} 2.51 ppm. The olefinic

protons (H-8', H-9') appeared as a multiplet at 5.32 ppm.

Compound **4** was then catalytically hydrogenated using Pd/C in methanol to give compound **5** (Scheme 2, *vide supra*) with the saturated C₁₅ side chain. The ¹H NMR spectrum of compound **5** exhibited signals for the aromatic protons at δ_H 6.73, 6.83 and 7.20 ppm as two doublets and a triplet of one proton each

carbons appeared at δ_C 156.29, 141.43, 130.22, 123.55, 121.52 and 108.40 ppm, while signals for the methoxy and the carbomethoxy carbons were observed at δ_C 55.89 and 52.09 ppm, respectively. A signal at δ_C 33.51 ppm was assigned to the benzylic carbon (C-1') while the peak at δ_C 31.17 ppm was assigned to the carbon next to the benzylic carbon (C-2'). The signal at δ_C 14.12 ppm was assigned to the terminal methyl carbon of the pentadecyl chain

while the methylene carbons next to it appeared at δ_C 22.71 ppm and the other twelve methylene carbons were put together at a chemical shift range of δ_C 29.71-29.83 ppm. These δ_C values are comparable to those reported by Logrado *et al.* (2010).



Scheme 2: Transformation of anacardic acid (**3**) to 4-methoxybenzofuran-1,3-dione (**10**).

for H-3, H-5 and H-4, respectively. Two singlets at δ_H 3.81 and 3.90 ppm were assigned for the methoxy (3H) and carbomethoxy (3H) protons, respectively. Logrado and co-workers (2010) reported that the signals for the two groups appeared at δ_H 3.91 and 3.92 ppm. The chemical shifts for the protons of the pentadecyl side chain of compound **5** were similar to that of compound **4** with the exception of the disappearance of the olefinic protons signal (at *ca.* 5 ppm). The ¹³C NMR spectrum fully agrees with the assigned structure. In the low field one resonance appears at δ_C 168.93 ppm, which is assigned to the quaternary carbonyl carbon of compound **5**. Six signals for the aromatic

Benzylic bromination of **5** with NBS yielded compound **6** (Scheme 2, *vide supra*) in 85% as a yellowish liquid. The ¹H NMR spectrum of bromide **6** had its aromatic protons signals appearing at δ_H 6.85, 7.22 and 7.41 ppm as two doublets and a triplet, respectively. Each of these signals represented one proton. Logrado *et al.* (2010) reported a slight difference in the chemical shifts of the same aromatic protons. Logrado observed that the signals for the aromatic protons appeared at δ_H 6.84, 7.21 and 7.38 ppm, respectively. A signal at δ_H 4.91 ppm (*t*, 1H) accounted for the proton at the benzylic position (H-1') carrying the bromine atom. The two singlets at δ_H 3.83 (3H) and 3.94 ppm (3H)

were assigned to the methoxy and carbomethoxy protons, respectively. A multiplet at δ_{H} 2.15 ppm was assigned to the H-2' methylene protons. A multiplet of two protons resonating at a chemical shift of 1.57 ppm was assigned to H-3' methylene protons while a multiplet at δ_{H} 1.25 ppm integrating for twenty two protons accounted for the remaining methylene groups.

Dehydrobromination of compound **6** using DBU gave the benzylic alkene **7** (Scheme 2, *vide supra*) in 60% yield as white crystals. Attempts to use trimethylamine as the base for the dehydrohalogenation reaction proved unsuccessful. The ^1H NMR spectrum for alkene **7** had its aromatic protons appearing at δ_{H} 6.78, 7.11 and 7.30 ppm as two doublets and one triplet, respectively, each integrating for one proton. A multiplet at δ_{H} 6.25 ppm accounted for the two olefinic protons. Logrado *et al.* (2010) reported a δ_{H} 6.24 ppm for the same protons, which is pretty close to the present results. The two singlets at δ_{H} 3.83 and 3.92 ppm, each representing three protons, were assigned to the methoxy and carbomethoxy protons, respectively. A quartet at δ_{H} 2.19 ppm is due to the two methylene protons at the allylic position (*i.e.*, H-3'). Next to it is a multiplet at δ_{H} 1.44 ppm assigned to the two homoallylic methylene protons. Whereas a broad multiplet at δ_{H} 1.26 was assigned to the remaining 20 methylene protons, a triplet at δ_{H} 0.86 ppm was assigned to the terminal methyl protons of the pentadecyl side chain.

Ozonolysis of the alkene **7** in dry DCM at -78°C resulted into aldehyde **8** (Scheme 2) as a white powder in 63% yield. In the IR spectrum of aldehyde **8** bands at 1733 and 3089 cm^{-1} are due to the C=O and $\text{sp}^2\text{ C-H}$ stretch, respectively. The ^1H NMR spectrum of aldehyde **8** showed that there was a shift in the position of the aromatic protons in the sense

that these protons were more deshielded and appeared at δ_{H} range of 7.21-7.57 ppm in contrast to alkene **7** which had its aromatic protons resonating at δ_{H} 6.76-7.3 ppm. These protons, each integrating to one, appeared as two doublets at δ_{H} 7.21 and 7.47 (for H-3 and H-5, respectively) and one triplet at δ_{H} 7.57 ppm (H-4). A singlet at δ_{H} 9.97 ppm was assigned to the aldehydic proton. Tu *et al.* (2013) reported a slightly different δ_{H} value of 10.36 ppm for the same aldehydic proton. The signals for the methyl protons of the $-\text{OCH}_3$ and $-\text{CO}_2\text{CH}_3$ groups appeared at δ_{H} 3.89 and 3.98 ppm, respectively. Moreover, the appearance of only 10 peaks in the ^{13}C NMR spectrum signified the absence of the C_{15} side chain. The most downfield signal at δ_{C} 190.05 ppm is due to the presence of the aldehydic C=O. The signal at δ_{C} 167.46 ppm was assigned to the C=O of the ester group. The six signals at δ_{C} 116.67, 122.49, 123.61, 130.84, 134.35 and 156.27 ppm are due to the aromatic carbons. The remaining up field signals at 52.55 and 56.28 ppm were assigned to the two methyl carbons of the $-\text{CO}_2\text{CH}_3$ and $-\text{OCH}_3$ groups, respectively.

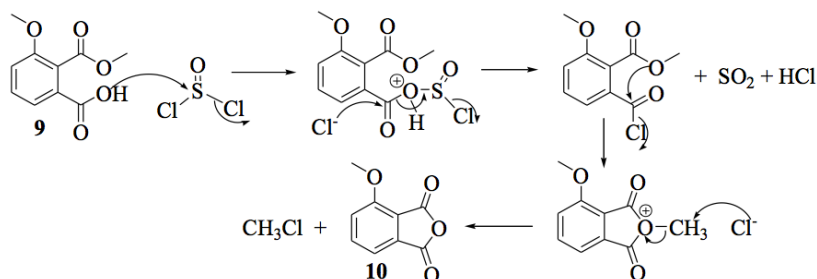
It is worth noting that Plourde and Spaetzel (2002) have reported values ranging from 191.1 to 191.3 ppm for the groups of analogous benzaldehydes. Moreover, Daquino *et al.* (2009) and Seo *et al.* (2012) have reported ^{13}C NMR signals appearing at δ_{C} 168 to 169.5 ppm due to benzoate ester C=O carbons. The aforementioned δ_{C} values are in close agreement to the corresponding values obtained for compound **8**. Aldehyde **8** is a useful starting fine chemical for entry into synthesis of quinones and anthraquinones natural products via the Hauser-Kraus annulation chemistry (Hauser *et al.* 2003, Hassan *et al.* 2015). Further oxidation of the aldehyde **8** with NaClO_2 in NaH_2PO_4 buffer formed carboxylic acid **9** (Scheme 2, *vide supra*) as white needle-

shaped crystals in 98% yield. In the IR spectrum of **9**, a broad peak was observed around 3513.54 cm^{-1} due to the carboxylic O–H stretch. The bands observed at 1736 cm^{-1} and 1235 cm^{-1} were due to the C=O and C–O stretch, respectively. Inspection of the ^1H NMR spectrum of compound **9** indicated that the aldehydic proton had disappeared. The aromatic protons appeared as two doublets at δ_{H} 7.15 and 7.70 and a triplet at δ_{H} 7.49 ppm for H-4, H-5 and H-6, respectively.

The methyl protons for $-\text{OCH}_3$ and $-\text{CO}_2\text{CH}_3$ groups appeared at δ_{H} 3.88 and 3.94 ppm, respectively. These δ_{H} are similar to those reported by Gupta *et al.* (1987) for the same compound. In the case of aldehyde **8**, it was noted that the aromatic proton appearing as a triplet (H-5) was more deshielded ($\delta_{\text{H}} = 7.57$ ppm). However, the same proton (H-5) in compound **9** was less deshielded and appeared as triplet at δ_{H} 7.49 ppm. Conversely, H-4 was

more deshielded in compound **9** ($\delta_{\text{H}} = 7.70$ ppm) than it was the case in compound **8** ($\delta_{\text{H}} = 7.47$ ppm), which is probably due to the increase in partial positive charge on the carbonyl carbon of the carboxyl group.

The ^{13}C NMR spectrum displayed signals at δ_{C} 168.18 and 169.94 ppm due to the two carbonyl carbons of the carboxyl and ester (benzoate) groups, respectively. Daquino *et al.* (2009) and Kiran *et al.* (2013) reported ^{13}C NMR signals appearing at δ_{C} 172.3 and 164.1–166.9 ppm due to carboxyl and benzoate C=O carbons, respectively, values which are in close agreement to the corresponding values obtained for compound **9**. Six signals due to the aromatic carbons were observed at δ_{C} 115.45, 122.72, 125.45, 128.18, 130.01 and 156.36 ppm. The more up field signals due to the methoxy carbons for $-\text{OCH}_3$ and $-\text{CO}_2\text{CH}_3$ groups appeared at δ_{H} 52.72 and 55.45 ppm, respectively.



Scheme 3: Mechanism for the SOCl_2 mediated formation of compound **10**.

Several methods were attempted to convert compound **9** to phthalic anhydride **10** including heating compound **9** under high vacuum, heating at $70\text{ }^\circ\text{C}$ in the presence of dilute H_2SO_4 and treatment of **9** with thionyl chloride at $70\text{ }^\circ\text{C}$. Unreacted starting material was recovered in the first two attempts. However, treatment of compound **9** with thionyl chloride gave the

desired anhydride **10** in near quantitative yield. The foregoing observation suggests that successful cyclization of **9** upon treatment with SOCl_2 is facilitated by formation of the acid chloride with a very good leaving group which is easily attacked by the methoxy group of the ester as indicated in Scheme 3.

The ^1H NMR spectrum of compound **10** displayed a singlet at δ_{H} 4.08 ppm (3H) due the methoxy group. Gupta *et al.* (1987) and Liu (2004) also observed that protons for the same methoxy group appeared at the same chemical shift, *i.e.*, δ_{H} 4.08 ppm. The signals due the aromatic protons appeared as two doublets at δ_{H} 7.33 and 7.59 ppm and a triplet at δ_{H} 7.85 ppm, which are assigned to H-5, H-6 and H-7, respectively. Liu (2004) reported that the aromatic protons for 3-methoxyphthalic anhydride appeared at δ_{H} range of 7.3-7.8 ppm. The signal due to H-6, which is a triplet, appeared in the low field (δ_{H} = 7.85 ppm) in compound **10** compared to its position (δ_{H} = 7.49 ppm) in compound **9**. The ^{13}C NMR spectrum of the anhydride **10** displayed nine peaks; with peaks at δ_{C} 160.36 and 162.59 ppm being due to the two quaternary carbonyl carbons. The six aromatic carbon atoms had their signals appearing at δ_{C} 116.36, 117.48, 118.60, 132.54, 138.36, and 157.52 ppm. The signal for the methoxy carbon appeared at δ_{C} 56.65 ppm.

CONCLUSIONS

The authors have reported previously on the utilization of anacardic acid and cardanol components of *n*CNSL in the synthesis of dyes, a detergent, a kairomone component and other useful chemicals. The chemistry reported in this paper has demonstrated once again the versatility of cashew nut shell liquid as a renewable natural resource for synthesis of fine and industrial chemicals. Accordingly, further synthetic work on the use of cardanol and cardol, the other major components of CNSL, as starting material for synthesis of fine chemicals and natural products is in progress and will be reported in due course.

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