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Methoxyphenanthrenes: synthesis and structure analysis

Osman Çakmak [1*], Seda Duman [2] and Kıymet Berkil Akar [2]

[1]*Department of Gastronomy and Culinary Arts, Faculty of Arts Design and Architecture Istanbul Rumeli University, Silivri, Istanbul, Türkiye*

[2]*Department of Chemistry, Faculty of Science and Letters, Tokat Gaziosmanpaşa University, Tokat, Türkiye*

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Abstract: The phenanthrene bromide product mixture obtained from bromination of 9-bromophenanthrene **1**, which could not be separated chromatographically, was converted to chromatographically separable methoxy products (**3a-d**) with CuI catalyzed methoxylation reaction. The resulting products were purified by chromatographic method and detailed structure analysis of the products was done by NMR spectroscopy. Two-dimensional NMR spectroscopy methods can be used successfully to elucidate the structures of methoxyphenanthrene derivatives. With the combination of APT, DEPT 90, HETCOR, HMBC, COSY and NOESY spectral data, the position of the substituents was easily determined. In particular, the HMBC and NOESY spectra provide critical information about the positions of the bounded groups. Further bromination reactions of 1,9-dimethoxide **3a** selectively gave brominated compound **4**.

Keywords: Bromophenanthrene; methoxyphenanthrene; bromination; 2D NMR.

1. Introduction

There are many natural molecules with phenanthrene or reduced phenanthrene core structure that show biological activity and have therapeutic properties. For example, steroids such as cholesterol and sex hormones, resin acids, alkaloids such as morphine and aporphine, di- and triterpenoids phenanthrenes are some of the molecules in the skeletal structure. Most of the natural phenanthrenes are monomeric, with hydroxy and/or methoxy derivatives being the majority.

Phenanthrenes, which constitute an important class of organic compounds, are widely found in nature[1-3] and are used as intermediates in the synthesis of natural compounds.[4] Floyd et al. (1976),[4] the synthesis of phenanthrene derivatives and their synthesis methods are discussed in the literature review. As seen in these literatures, we do not see the method of derivatization starting from phenanthrene skeleton structure.

In phenanthrene, there are 10 different positions where bromine atoms can be attached. As a result of bromination of phenanthrene, 25 di-, 61 tri-, and 10 tetrabromophenanthrene derivatives can be formed. Since the isomeric multiplicity, studies aimed at increasing the selectivity in the production of bromophenanthrenes come into prominence and gain importance. So far, there has been no significant development in this field.

In our group studies, it was shown that aromatic compounds can be brominated by using less solvent as well as prolonging reaction time without using Lewis acid catalysts such as iron in bromination reactions. The longer the reaction time, the greater the selectivity. At the same time, temperature, the use of different solvents, and the use of support catalyst increase selectivity. Likewise, the amount of bromine and the radicalic conditions in the presence of light, change the selectivity, yield

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and reactivity in the reactions. Likewise, the amount of bromine and the radicalic conditions in the presence of light change the selectivity, yield and reactivity in the reactions.

Bonded bromine atoms are in the same plane as the ring in aromatic compound. In this case, there is no polarity difference amongst isomer bromides. Chromatographic separation does not work in these studies. For this reason, the separation of is the most important problem for aromatic bromides.

Cakmak et al. in their research for many years, they developed efficient methods on the selective and multiple bromination (polybromination) of especially inactive aromatic compounds such as naphthalene,[5,6] anthracene,[7-9] biphenylene,[10] quinoline.[11]

It was seen that bromo product ratios are dramatically changed depending on the reaction conditions and parameters as seen careful NMR studies. However, attempts at chromatographic separation of isomers failed each time due to nearly the same Rf values of bromo compounds.[12,13]

In this study, it is aimed to indirectly determine the structures of the bromination product mixture by converting it to the methoxy derivatives. For this purpose, brominated products of 9-bromphenantrene were subjected to copper-catalyzed methoxy reaction. The Compounds were subjected to separation by column chromatography. Extensive NMR spectroscopic examinations were made on the structures.

2. Experimental

2.1. Chemical Material and Apparatus

Reagents and solvents were purchased from Aldrich Chemical Company. Melting points were determined on an Electrothermal IA9100 digital melting point apparatus. A Jasco 430 FT/IR spectrometer was used to record the IR spectra. ^{1}H and ^{13}C NMR spectra were recorded on a Bruker Avance DPX 400 MHz spectrometer at 400 MHz and 100 MHz, respectively. Mass spectra were recorded on an Agilent 6890 N GC and Perkin Elmer Clarus 500 GC system spectrometers.

2.3. Chemistry

*2.3.1. Bromination of 9-Bromophenanthrene **1** with 3 Equivalent Molecular Bromine*

9-Bromophenanthrene **1** (2 g, 7.78 mmol) was dissolved in acetonitrile (20 mL) by heating and allowed to cool slowly to room temperature without shaking to avoid precipitation. Then, molecular bromine (24.1 mmol) was added to this solution via syringe after the flask was wrapped with aluminium foil. The resulting reaction mixture was then left to stand at room temperature for 2d. The resulting precipitate was collected by filtration. The solvent was removed in *vacuo* to give a white solid (2.79 g) whose ^{1}H-NMR spectrum showed a bromophenanthrene mixture **2**. The resulting mixture was used for the next step.

*2.3.2. Synthesis of Methoxy Phenanthrene Derivatives (**3a-d**)*

Freshly cut sodium (2.313 g, 0.101 mol) was added under argon atmosphere to the dry methanol (80 mL) at 0 °C. After the dissolution was completed, the solution was diluted with dry dimethylformamide (40 mL) and then vacuum-dried cuprous iodide (2,394 g, 0,013 mol) was added. To this mixture was added a solution of bromophenanthrene mixture (**2**) (3.104 g). The resulting mixture was stirred under argon atmosphere and refluxed for 7d. The mixture was cooled to room temperature and after addition of water, the obtained solution extracted with chloroform. The organic layer was dried over sodium sulphate and the solvent removed in *vacuo*. The crude product was purified by silica gel (150 g) column chromatography, eluting with a gradient mixture of 5 to 10% ethyl acetate in hexane to afford four compounds (**3a-d**).

*1,9-Dimethoxyphenanthrene (**3a**)*: White needle, yield 13%, mp 107-108 °C; ^{1}H NMR: ™ 8.68 (dd, J_{56}= 8 Hz, J_{68}= 1.2 Hz, 1H), 8.42 (d, J_{87}= 8.0 Hz, 1H), 8.23 (d, J_{43}= 8 Hz, 1H), 7.73-7.64 (m, 2 H), 7.51 (s, 1H), 7.47 (t, J_{32}= 8 Hz, 1H), 7.02 (d, J_{23}= 8.0 Hz, 1H), 4.16 (C_9-OCH_3, 3H), 4.08 (C_1-OCH_3); ^{13}C NMR: 154.9, 153.3, 131.2, 127.5, 127.0, 126.6, 126.4, 124.1, 123.9, 123.1, 122.5, 115.0, 106,1, 95.8, 55.7 (C_1-

OCH_3), 55.5 (C_9-OCH_3); IR (KBr, cm^{-1}) ν_{max} 3099, 3062, 3012, 2996, 2967, 2938, 2906, 2838, 1887, 1695, 1623, 1596, 1577, 1523, 1494, 1471, 1450, 1432, 1417, 1390, 1365, 1303, 1274, 1251, 1238, 1213, 1157, 1108, 1085, 1018, 981, 952, 883, 848, 798, 775, 763, 748, 725, 694, 636.

*3,9-Dimethoxyphenanthrene (**3b**)*: White rod-like, yield 5%, mp 104-105 °C; ^{1}H NMR: δ 8.61 (d, J_{87}= 8 Hz, 1H), 8.39 (d, J_{56}= 7,6 Hz, 1H), 8.01 (d, J_{42}=1.6 Hz, 1H), 7.72 (d, J_{12}= 8.8 Hz, 1H), 7.70-7.65 (m, 2H), 7.24 (dd, J_{21}= 8.8 Hz, J_{24}=2.4 Hz, 1H), 6.98 (s, 1H), 4,09 (C_3-OCH_3, 3H), 4,03 (C_9-OCH_3, 3H); ^{13}C NMR: δ 156.8 (C-OCH_3), 152.0 (C-OCH_3), 130.7, 128.6, 127.5, 127.3, 126.8, 126.7, 126.5, 122.6, 122.5, 116.8, 104.3, 101.8, 55.5 (OCH_3), 55.4 (OCH_3); IR (KBr, cm^{-1}) ν_{max} 3099, 3070, 3010, 2964, 2958, 2911, 2830, 2076, 1901, 1797, 1700, 1617, 1597, 1577, 1506, 1465, 1448, 1432, 1396, 1365, 1332, 1301, 1236, 1182, 1147, 1112, 1097, 1035, 983, 937, 900, 854, 831, 811, 771, 754, 717, 582.

*1-Bromo-9-methoxyphenanthrene (**3c**)*: *White* needle, yield 1%, mp 101-102 °C; ^{1}H NMR: δ 8.64 (d, J_{43}= 8 Hz, 1H), 8.57 (d, J_{56}= 8.4 Hz, 1H), 8.41 (d, J_{23}= 8 Hz, 1H), 7.86 (d, J_{87}= 7.2 Hz, 1H), 7.77-7.66 (m, 2H), 7.45 (s, 1H), 7.35 (dd, J_{32}= 8 Hz, J_{34}= 7.6 Hz,1H), 4.17 (OCH_3, 3H); ^{13}C NMR: δ 154.9, 131.6, 131.1, 130.9, 128.1, 127.6, 127.0, 126.5, 124.4, 122.8, 122.7, 122.2, 122.1, 100.9, 55.6 (OCH_3).

*1,3-Dibromo-9-methoxyphenanthrene (**3d**)*: White needle, yield 3%, mp 103-104 °C; ^{1}H NMR: δ 8.71 (s, 1H), 8.57 (d, J_{56}= 8.4 Hz,1H), 8.38 (d, J_{87}= 8 Hz, 1H), 7.73-7.64 (m, 2H), 7.64 (s, 1H), 6.93 (s, 1H), 4.12 (OCH_3, 3H); ^{13}C NMR: δ 154.8 (C-OCH_3), 132.3, 131.0, 130.7, 129.6, 128.7, 128.3, 127.8, 127.5, 126.1, 123.4, 123.3, 118.7, 102.0, 55.8 (OCH_3); IR (KBr, cm^{-1}) ν_{max} 3068, 3004, 2965, 2935, 2830, 2108, 1965, 1900, 1802, 1750, 1693, 1623, 1602, 1587, 1516, 1488, 1460, 1428, 1395, 1294, 1280, 1229, 1193, 1150, 1123, 1099, 1041, 1009, 983, 948, 882, 843, 804, 760, 715, 673, 621, 580, 524, 501, 476, 438, 425, 414.

*2.3.3. Bromination of 1,9-Dimethoxyphenanthrene (**3a**) with 1 Equivalent Molecular Bromine*

1,9-Dimethoxyphenanthrene (**3a**) (80 mg, 0.336 mmol) was dissolved in CH_2Cl_2 (2 mL) in a test tube, and then molecular bromine (59 mg, 0,37 mmol) was added dropwise via syringe. The resulting reaction mixture was then left to stand at 5 °C for 5d and the amount of solvent was kept constant during this reaction. Crystal formation was observed during the reaction. The solvent was removed in *vacuo* and the solid crude product was recrystallized from CH_2Cl_2 to give 3-bromo-1,9-dimethoxyphenanthrene (**4**).

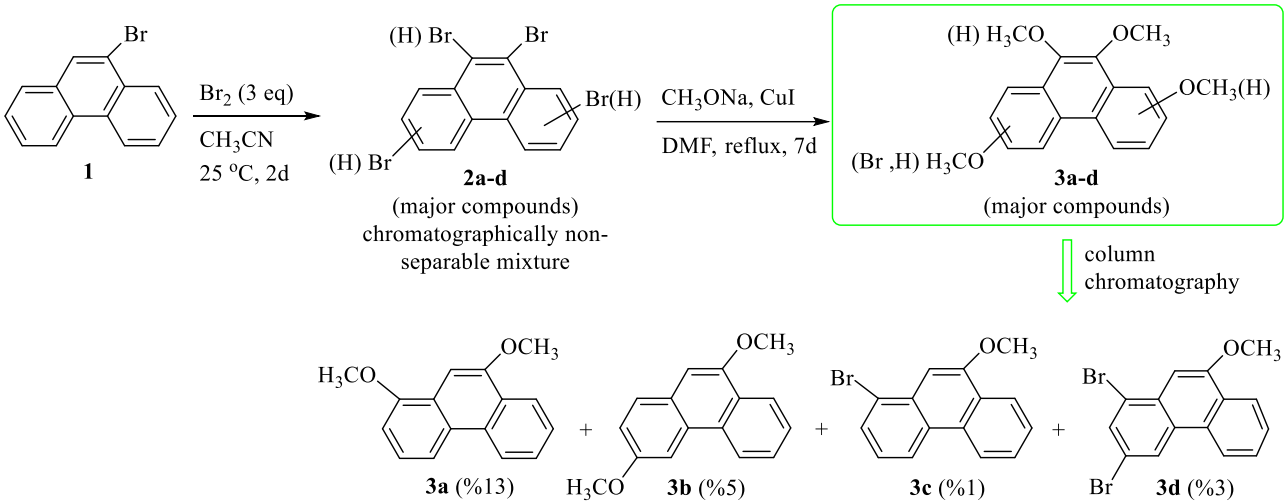
*3-Bromo-1,9-dimethoxyphenanthrene (**4**)*: Light yellow column, yield 94%, mp 152-154 °C; ^{1}H NMR: δ 8.54 (dd, J_{56}=8.0 Hz, J_{57}=1.2 Hz, 1H), 8.38 (dd, J_{78}=8 Hz, J_{68}=1.6 Hz, 1H), 8.33 (d, J_{24}=1.4 Hz,1H), 7.71-7.66 (m, 2H), 7.39 (s, 1H), 7.09 (d, J_{24}=1.4 Hz,1H), 4.12 (OCH_3, 3H), 4.06 (OCH_3, 3H); ^{13}C NMR: δ 155.4, 153.5, 130.1, 128.4, 127.3, 127.0, 126.9, 123.0, 122.7, 122.6, 117.8, 117.6, 109.8, 95.5, 55.9 (C_1-OCH_3), 55.5 (C_9-OCH_3).

3. Results and Discussion

3.1. Chemistry

9-Bromophenanthrene **1** was reacted with 3 equivalent moles of bromine in solvent medium at a ratio of 1:50 substrate to solvent. The mixture was left to stand for 2 days in the dark at room temperature.

The phenanthrene bromide mixture **2** formed was treated with sodium methoxide in the presence of copper catalysis (CuI). The product mixture obtained was subjected to separation by column chromatography. Initially, hexane was used as eluant, followed by a hexane-ethyl acetate solvent system. Four products were isolated. The amount of 9-bromphenanthrene (**1**) was taken as the basis for calculating the yield of the reaction (Scheme 1).



Scheme 1. Conversion of the phenanthrene bromide mixture **2** to methoxyphenanthrene isomers

Particles of sodium (2.313 g, 0.101 mol) in hexane in a beaker were added to the reaction flask containing dry methanol (80 mL) under an argon atmosphere. Metallic sodium particles dissolved completely within 20 minutes in the reaction flask cooled by ice bath (0-5 °C). Dry DMF (40 mL) and phenanthrene bromide mixture **2** (3.104 g) dissolved in DMF (40 mL) were added to the solution. Finally, freshly dried CuI (2.394 g, 0.013 mol) was added in *vacuo*. After 3 days under reflux, it was determined that the starting material bromides were consumed in the medium (TLC examination). The boiling process was continued for 4 more days in order to convert the second bromides in the structure into methoxides.The crude product (1.22 g, methoxyphenanthrene mixture **3a-d**) obtained after filtration and extraction was subjected to column chromatography. For the purification of synthesized compounds, silica gel 60 (230 – 400 mesh) (150 g), was used as column filter. Initially, hexane was used as the promoter. The polarity was increased regularly. From the 30th fraction, the running ethyl acetate-hexane ratio is 5%; made 10% from fraction 40. A total of 55 fractions in ~40 mL volumes were collected (total amount of spent solvent was 3 L), and four products were isolated as pure as a result of the chromatographic process (Scheme 1). The following compounds were isolated from the column chromatographic process.

*1,9-Dimethoxyphenanthrene (**3a**):* mp;107-108 °C, R_f; 0.48 (10% EtOAc/Hexane), yield; 13%, off-white needle crystals,

*3,9-Dimethoxyphenanthrene (**3b**):* mp;104-105 °C, R_f; 0.34 (5% EtOAc/Hexane), yield; 5%, white rod like crystals.

*1-Brom-9-methoxyphenanthrene (**3c**):* mp;101-102 °C, R_f; 0.30 (Hexane), yield; 1%, white fine crystals.

*1,3-Dibromo-9-methoxyphenanthrene (**3d**):* mp;103-104 °C, R_f; 0.25 (Hexane), yield; 3% white needle crystals.

Notes and some observations: In Experiment 3.3, the bromination time should be kept for 3 days instead of 2 days in order to obtain more trimethoxy derivatives instead of dimethoxy products in the reaction. Longer methoxylation time is needed for complete replacement of all bromine groups with methoxy groups.

3.2 Spectroscopic Studies

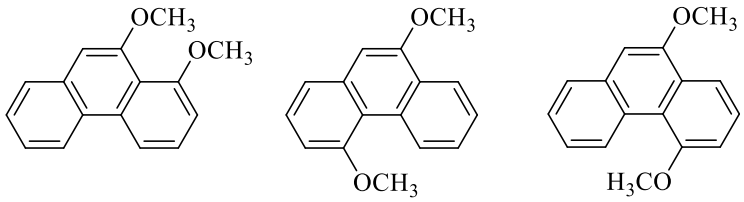
*3.2.1. 1,9-Dimethoxyphenanthrene (**3a**)*

Results of the NOESY examination of compound **3a** confirm that the resonance signal on the right (7.02, d, J_{23} = 8.0 Hz, 1H) belongs to H_2. In the NOESY spectrum, there is a correlation of both C_1-OCH_3 and C_9-OCH_3 with the C_9-OMe group H_{10} proton (δ 7.51). Interestingly, the C_9-OMe group does not show correlation with H_8. According to the NOESY spectrum, there may be a preference for a conformer structure in which the methyl group C_9-OMe shares the same space with the H_{10} proton but not with H_8 in the most stable form of the molecule (Figure S3). Finally, correlations with the H_3-H_4 and H_5-H_6 proton confirm the proposed structure.

We can attribute the shifting of H_{10} to a lower field than H_2 to the steric effect of C_1-OMe group. With the same justification (the effect of C_9-OMe), there is a lower field resonance than H_8, H_6 and H_7. Singlet peaks of OMe groups observed at 4.16 and 4.08 (Table 1). While methyl carbons of the methoxy groups resonate at δ 55.7 and 55.5, quaternary carbon atoms to which the methoxy groups are attached resonate at 153.3 ppm at δ 54.9 (s). As it is known, quaternary carbon atoms with attached methoxy groups resonate in a lower field than other carbon atoms (C_{10} and C_2, Table 2).

The HMBC spectrum of the compound shows proton-carbon atom interactions over two, three, and even four bonds. When we examine the signal of the H_2 proton in Figure S5, we can see the interactions (correlations) with the C_3 carbon atoms over two bonds, and the C_4 and C_1 carbon atoms over three bonds. Likewise, the interactions of the signal of the H_4 proton with C_2 (three bonds), C_3 (two bonds) and quaternary carbons (two bonds) are clearly noticeable. The existing relationships of the H_{10} proton with C_9 (2 bonds), C_1 (three bonds) and quaternary carbon atoms (two and three bonds) are also observed in the HMBC spectrum. According to these results, it is certain that the methoxy group is bound to the C_1 atom. In addition, the correlations observed between the interactions δ 4.16 - δ_C 153.3 and δ 4.08 - δ_C154.9 methoxy protons and the quaternary carbon atoms to which the methoxy groups are attached are other confirmations for the positions of the methoxides Table 2.

Scheme 2 shows other possible methoxyphenanthrene structures (**5**-**7**). However, ^{1}H NMR, especially HMBC and NOESY spectra do not support these three structures. Let's just say that in the HMBC spectrum of the compound, the interaction of the H_{10} proton with C_9 (two bonds) and C_1 (three bonds) MeO-C is clearly visible (Figure S5). The correlation of the H_2 proton over three bonds and the H_3 proton with the C_1 carbon atom over four bonds does not comply with the structures in Figure S5. If the compound had a structure of **5**, there would be a H_1-C_9-OMe correlation over four bonds.



5 **6** **7**

Scheme 2. Possible structures of dimethoxyphenanthrene

*3.2.2. 3,9-Dimethoxyphenanthrene (**3b**)*

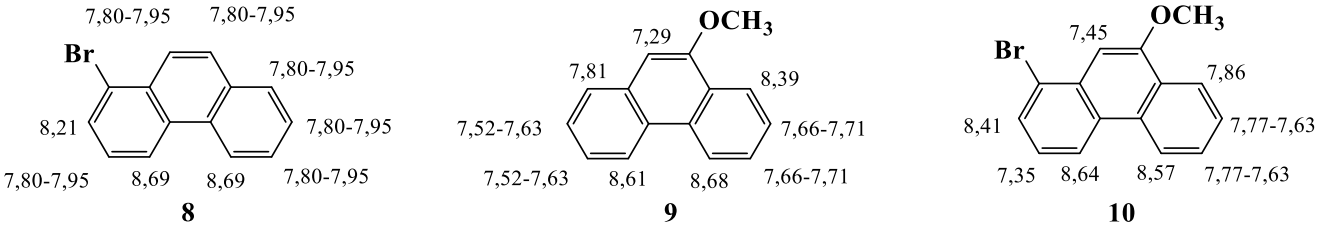
In the 3,9-dimethoxyphenanthrene (**3b**), the H_{10} proton resonated in a higher field (δ 6.98 ppm) compared to 1,9-dimethoxy **3a** (6.98 ppm), while the H_2 proton shifted to a lower field (δ 7.24 ppm) (Figure S7). This proton was split into the doublet of doublet by interacting with the H_2 proton vicinal and the H_4 proton meta. The signal of the H_4 proton, interacting with the H_2 proton meta, shifted quite downward at δ 8.01 ppm. This proton (H_4) shifted higher than the proton of 1,9-dimethoxy **3a** (δ 8.23 ppm). This situation can be explained by the neighboring methoxy group providing more electrons (shielding).

The δ C 55.5 and δ C 55.4 MeO signals and the δ C 156.8 and δ C 152.0 quaternary carbon signals observed in the ^{13}C NMR spectrum are compatible with two methoxy groups in the structure (Figure S8).

In the NOESY spectrum of the molecule (Figure S9), the correlation of C_3-OMe with both H_2 (black line) and H_4 (red line) is clearly seen in the spectrum. Correlation of C_9-OMe with H_{10} proton (yellow line) and H_8 proton (purple line) is compatible with the proposed structure (3,9-dimethoxyphenanthrene **3b**). Again, as expected, H_4-H_5 correlation is observed from the spectrum.

*3.2.3. 1-Brom-9-methoxyphenanthrene (**3c**)*

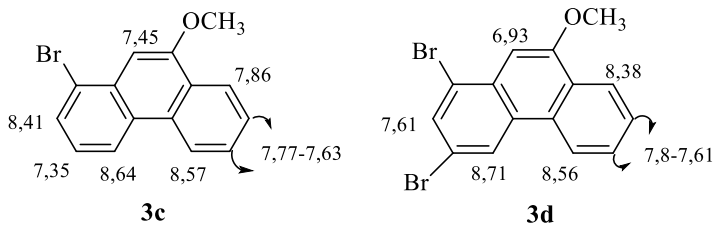
Comparative NMR analyzes of the three compounds (**8**, **9** and **10**) in Scheme 3 provide useful information about the structure of the 1-bromo-9-methoxy **10** compound. The H_{10} proton of 1-bromo-9-methoxyphenanthrene (**10**) is shifted lower than that of 9-methoxy phenanthrene (**9**). Because this proton is subjected to steric compression of bromine C_1-Br atom (Scheme 3). In 9-methoxy **9**, the resonance of the H_2 proton is a multiplet at δ 7.77-7.66 ppm, while in compound **10** it is doubled in a lower field (8.41 ppm, J_{23}= 8 Hz). H_4 and H_5 protons form similar signaling systems with 9-methoxyphenanthrene (**9**) (Scheme 3). H_4 and H_5 protons form resonance signals in phenanthrene structures at the far left (lower field) of the spectra due to steric compression. In 1-bromophenanthrene (**8**), H_6, H_7 and H_8 protons give overlapping (in the same region) resonance signals. Whereas, in 1-bromine-9-methoxy phenanthrene (**10**), the H_8 proton gives a distinct resonance signal (δ 7.86) in a fairly downstream area. We can attribute this, as expected, to the steric compression of the methoxy group.



Scheme 3. [1]H-NMR values of 1-bromophenanthrene (**8**)[14], 9-methoxyphenanthrene (**9**) and 1-bromo-9-methoxyphenanthrene (**10**)

*3.2.4. 1,3-Dibromo-9-Methoxyphenanthrene (**3d**)*

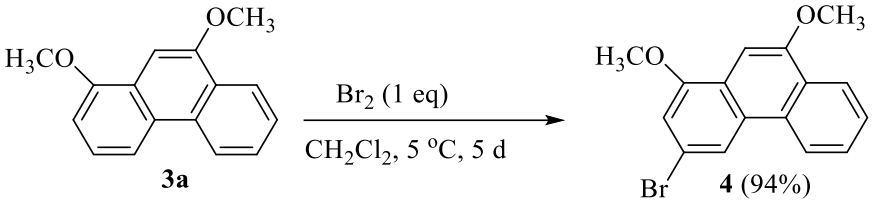
In the [1]H NMR spectrum (Figure S13) of compound **3d**, doublets (δ 8.57 and δ 8.38) and two triplets (δ 7.73-δ 7.64 ppm) indicate the absence of bromine atoms in a ring (H_5-H_8 protons). The presence of two singlet signals other than the one belonging to H_{10} indicates that the bromine atom is attached to the other ring in the meta-position. The resonance of the H_4 proton in compound **3d** in the lower field (8.71, s, 1H) compared to H_5 can be attributed to the presence of two electron-withdrawing bromine atoms in the respective ring (Scheme 4). The [1]H-NMR spectrum shows one methoxy group in the structure (Table 1). The presence of one methoxy methyl (δ_C 55.8) and one methoxy bonded carbon atom (δ_C 154.8) is confirmed in the [13]C NMR spectrum. Again, in [13]C NMR (Figure S14), the observation of the seven quaternary carbons resonance signal matches the structure.



Scheme 4. [1]H-NMR values of 1-bromo-9-methoxyphenanthrene (**3c**) and 1,3-dibrom-9-methoxyphenanthrene (**3d**)

*3.2.5. 3-Bromo-1,9-Dimethoxyphenanthrene (**4**)*

Each of the obtained methoxyphenanthrenes (**3a-d**) are the starting compounds in the further functionalization of phenanthrene. In order to determine and demonstrate this potential, the reaction of 1,9-dimethoxyphenanthrene (**3a**) with bromine was investigated. 1,9-Dimethoxy **3a** was reacted with one equivalent mole of molecular bromine. Instead of the expected product (ortho or para), a meta product was formed instead of attach to the activated carbons C_{10}, C_2 and C_4 (Scheme 5).



Scheme 5. Synthesis of 3-bromo-1,9-dimethoxyphenanthrene (**4**)

When we compare the chemical shift values of the starting compound (**3a**) with the brominated product **4**, the signal of H_3 proton (δ 7.47) in the new structure will disappear, and the signals of H_2 and H_4, which are doublet in the starting compound, will be singlet in the product. There are no obvious changes in the peak systems of the other ring and both compounds will exhibit similar signal systems. Consistent with the structure, H_{10}, H_2 and H_4 protons are singlet, H_5 and H_8 protons are doublets, and H_6 and H_7 protons (overlapped) are triplets (Figure S15).

The presence of seven CH signals observed in the DEPT 90 spectrum (Figure S17) of molecule **4** indicates that only one bromine atom is attached to the structure. The overlapping (or very close to each other) signal of several carbon atoms makes it difficult to identify carbon atoms with the help of the HETCOR spectrum (Figure S18). The structure of the compound **4** was determined beyond any doubt from the combinations of DEPT 90, which eliminates quaternary carbon atoms, HETCOR, which determines CH signals, and HMBC spectra (Figure S19), which allows the identification of carbon atoms (C_6 and C_7) to which the overlapped resonant protons (H_6 and H_7) are attached. The H_4 singlet resonates downstream due to gamma-gauche interaction. In the HMBC spectrum, the H_{10} proton correlates with the C_1 and C_9 carbons, and the H_2 proton correlates only with the C_1 carbon. In addition, H_2 interacts with carbons C_3 and C_4. The overlapping protons that could not be determined by the HETCOR spectrum were determined by detecting the interaction of C_7 with H_8 and C_6 with H_5 from the CH carbons (C_6 and C_7) to which these protons are attached. The interactions of H_{10}, H_8 and H_4 protons with quaternary carbon atoms allowed us to recognize all carbon atoms in the structure.

According to the results, the 2,9- and 3,9-dibromo phenanthrene produce as main products from bromination of 9-bromophenanthrene. There is difficulty in determining the structure of phenanthrene derivatives. In this study, we accomplished identification of structures and revealed a successful example of the use of two-dimensional NMR (HMBS and NOESY) in the structural analysis of phenanthrene derivatives.

Table 1. ^{1}H NMR values of methoxyphenanthrenes

Compound	H_1	H_2	H_3	H_4	H_5	H_6	H_7	H_8	H_{10}	OCH_3
3a		7.02 (d, J_{23}= 7.6)	7.47 (t, J_{32}=8)	8.23 (d, J_{43}= 8)	8.68 (dd, J_{56}= 8, J_{68}= 1.2)	7.73-7.64 (m)	7.73-7.64 (m)	8.42 (d, J_{87}=8)	7.51 (s)	4.08 (C_1-OCH_3) 4.16 (C_9-OCH_3)
3b	7.72 (d, J_{12}=8.8)	7.24 (dd, J_{21}= 8.8, J_{24}=2.4)		8.01 (d, J_{42}=1.6)	8.39 (d, J_{56}=7.6)	7.70-7.65 (m)	7.70-7.65 (m)	8.61 (d, J_{87}= 8)	6.98 (s)	4.09 (C_3-OCH_3) 4.03 (C_9-OCH_3)
3c		8.41 (d, J_{23}=8)	7.35 (dd, J_{32}=8, J_{34}=7.6)	8.64 (d, J_{43}=8)	8.57 (d, J_{56}=8,4)	7.77-7.66 (m)	7.77-7.66 (m)	7.86 (d, J_{87}=7.2)	7.45 (s)	4.17 (OCH_3)
3d		7.64 (s)		8.71 (s)	8.57 (d, J_{56}=8.4)	7.73-7.64 (m)	7.73-7.64 (m)	8.38 (d, J_{87}=8)	6.93 (s)	4.12 (OCH_3)
4		7.09 (d, J_{24}=1.4)		8.33 (d, J_{24}=1.4)	8.54 (dd, J_{56}=8.0, J_{57}=1.2)	7.71-7.66 (m)	7.71-7.66 (m)	8.38 (dd, J_{78}=8, J_{68}=1.6)	7.39 (s)	4.12 (OCH_3) 4.06 (OCH_3)

*Measured *J* values are given in parenthesis as Hz. s: singlet, d: doublet, dd: doublet of doublet, m: multiplet

Table 2. ^{13}C NMR values of methoxyphenanthrenes

Compound	^{13}C NMR Chenical Shift
3a	154.9 (C_1), 106.1 (C_2), 124.1 (C_3), 115.0 (C_4), 123.9 (C_5), 126.4 (C_6 or C_7), 127.0 (C_6 or C_7), 122.5 (C_8), 153.3 (C_9), 95.8 (C_{10}), 131.2 (C_{4a}), 127.5 (C_{4b}), 126.6 (C_{10a}), 123.1 (C_{8a}), C_1-OCH_3 (55.7), C_9-OCH_3 (55.5)
3b	156.8 (C-OCH_3), 152.0 (C-OCH_3), 130.7, 128.6, 127.5, 127.3, 126.8, 126.7, 126.5, 122.6, 122.5, 116.8, 104.3, 101.8, 55.5 (OCH_3), 55.4 (OCH_3)
3c	154.9, 131.6, 131.1, 130.9, 128.1, 127.6, 127.0, 126.5, 124.4, 122.8, 122.7, 122.2, 122.1, 100.9, 55.6 (OCH_3)
3d	154.8 (C-OCH_3), 132.3, 131.0, 130.7, 129.6, 128.7, 128.3, 127.8, 127.5, 126.1, 123.4, 123.3, 118.7, 102.0, 55.8 (OCH_3)
4	δ 155.4, 153.5, 130.1, 128.4, 127.3, 127.0, 126.9, 123.0, 122.7, 122.6, 117.8, 117.6, 109.8, 95.5, 55.9 (C_1-OCH_3), 55.5 (C_9-OCH_3)

4. Conclusion

The poly brominated phenanthrene product mixture **2** was reacted with CuI catalyzed NaOMe to form separable methoxy phenanthrene products. The products were purified by chromatographic method and detailed structure analysis of the products was done by NMR spectroscopy.

One-dimensional NMR measurements will not be sufficient to determine the structures of phenanthrene isomers. However, two-dimensional NMR spectroscopy methods were applied successfully to elucidate the structures of phenanthrene derivatives. With the combination of APT, DEPT 90, HETCOR, HMBC, COESY and NOESY spectral data, the positions of the substituents were easily determined. In particular, the HMBC and NOESY spectra provide critical information about the positions of the bounded groups.

The bromophenanthrenes mixture, which could not be separated chromatographically, was converted to chromatographically separable methoxy products. These studies reveal that phenanthrene derivatives will be synthesized indirectly from the bromophenantrene mixture. Thus, important fields of study were opened up for next studies.

Bromination reactions of 1,9-dimethoxide **3a** selectively gave brominated compound. Thus, it has been shown that the methoxy phenanthrene can be brominated regioselectively. Another result of these studies is that the method can be generalized in where other derivatives can be obtained from substitution reaction of mixture of phenanthrene bromide isomers.

First, the isomeric bromophenanthrene product mixture obtained from the bromination of 9-bromophenantrene shows that the mixture of isomers forms isolates methoxy derivatives, which demonstrates that this methodology can be applied to other substitution reactions.

Secondly, obtaining selectively brominated products from the bromination of 1,9-dimethoxyphenanthrene shows that other methoxyphenanthrenes can also be selectively brominated. The preliminary studies indicated that, the bromophenanthrenes may be multi-functional agent. Studies continue to increase the yield and optimize the reaction conditions.

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Supporting Information

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ORCID

Osman Çakmak: 0000-0001-9293-5572
Seda Duman: 0000-0002-0578-8576
Kıymet Berkil Akar: 0000-0001-9993-9541

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