

Design and Crystal Structures of Two New Compounds Fused with 3,4,5-Trimethoxybenzyl Group and 6,10-Dioxaspiro Group

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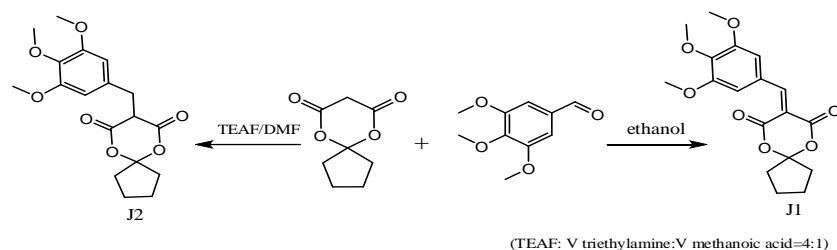
Abstract: Two new compounds, 8-(3,4,5-trimethoxybenzylidene)-6,10-dioxaspiro[4,5]decane-7,9-dione (**J1**) and 8-(3,4,5-trimethoxybenzyl)-6,10-dioxaspiro[4,5]decane-7,9-dione (**J2**) have been designed and generated by the reaction of 3,4,5-trimethoxybenzaldehyde with 6,10-dioxaspiro[4,5]decane-7,9-dione in different solvents. The 3,4,5-trimethoxybenzyl group of the two compounds connects with the dioxaspiro group via double bond (**J1**) and single bond (**J2**), respectively. The crystal structure determinations show that Compound **J1** belongs to the triclinic system, space group P-1 with $a = 5.4056(11)$ Å, $b = 11.465(2)$ Å, $c = 13.502(3)$ Å, $\alpha = 92.06(3)^\circ$, $\beta = 91.35(3)^\circ$, $\gamma = 93.50(3)^\circ$, $C_{18}H_{20}O_7$, $M_r = 348.34$, $V = 834.4(3)$ Å³, $Z = 2$, $D_c = 1.386$ g/cm³, $F(000) = 368$. Compound **J2** is also of the triclinic system, space group P-1 with $a = 8.8778(18)$ Å, $b = 9.5285(19)$ Å, $c = 11.082(4)$ Å, $\alpha = 89.69(3)^\circ$, $\beta = 67.38(3)^\circ$, $\gamma = 81.68(3)^\circ$, $C_{18}H_{22}O_7$, $M_r = 250.36$, $V = 854.9(3)$ Å³, $Z = 2$, $D_c = 1.361$ g/cm³, $F(000) = 372$. Both compounds form three-dimensional network structures via C–H···O intra- and intermolecular hydrogen bonds.

Keywords: synthesis; crystal structure; 3,4,5-trimethoxybenzyl group; 6,10-dioxaspiro[4,5]decane-7,9-dione

1. Introduction

The design and synthesis of compounds containing the spiro ring framework have received much attention owing to their wide applications in medicine. For example, spiro-iminosugars with 1,2,3-triazole have shown glycosidase inhibitory activity as well as antifungal activity [1]. Spiro-oxindoles were identified as anti-breast cancer and potent antiproliferative agents [2–4]. Spirombandakamines possess strong antiprotozoal activity [5]. Spiro-thiazine derivatives act as antimycobacterial activity [6]. Recently, spiro compounds have also drawn much attention due to diverse applications in organic functional materials such as circularly polarized luminescence (CPL) materials [7], a new rhodamine-based chemosensor [8], organic light emitting diodes (OLEDs) [9], a high-performance electrophosphorescent device [10], a fluorescent switch [11], optical data storage [12], and so on.

For these reasons, for 10 years, our group has exploited several approaches to synthesize all kinds of spiro compounds [13–16]. In continuation of our work, two new compounds: 8-(3,4,5-trimethoxybenzylidene)-6,10-dioxaspiro[4,5]decane-7,9-dione (**J1**) and 8-(3,4,5-trimethoxybenzyl)-6,10-dioxaspiro[4,5]decane-7,9-dione (**J2**) have been prepared via different synthetic routes (Scheme 1). In comparison to our previously synthetic route of Compound **J1**, Compound **J2** was linked via single bond instead of double bond. In addition, their structures are also characterized by elemental analysis, IR, ^1H and ^{13}C NMR analysis, and single-crystal X-ray diffraction.



Scheme 1. Synthetic routes of **J1** and **J2**.

2. Materials and Methods

2.1. Physical Measurements

The IR spectra were recorded as KBr pellets with a Nicolet FT-IR 510P Spectrometer (Nicolet Instrument Inc., Madison, WI, USA). The analyses of C, H, and N were made on an Elementar Vario EL III elemental analyzer (Elementar, Hanau, Germany). ^1H NMR and ^{13}C NMR spectra were recorded on a Bruker Avance-500 spectrometer (Bruker, Elisabethhof, The Netherlands) with CD_3COCD_3 as the solvent. X-ray diffraction for Compounds **J1** and **J2** were performed on a Spider diffractometer (Rigaku, Tokyo, Japan).

2.2. Preparation of **J1** and **J2**

J1 is easily obtained by a literature known method [14]. A 100 mL round-bottomed flask was charged with 3,4,5-trimethoxybenzaldehyde (0.98 g, 5 mL), 6,10-dioxaspiro[4,5]decane-7,9-dione (0.85 g, 5 mL), and ethanol (15 mL). The mixture was stirred and refluxed for 2.5 h, and the solution was then cooled to generate the precipitate. Yield 31.3%, m.p.: 96.9–98.1 °C. Anal. Calcd. for $\text{C}_{18}\text{H}_{20}\text{O}_7$: C, 62.06; H, 5.79; Found: C, 62.18; H, 5.68. ^1H NMR (500 MHz, CD_3OCD_3): 7.65 (s, 2H, Ar-H), 8.19 (s, 1H, =CH–), 3.83 (s, 9H, –OCH₃), 2.0–2.15 (m, 4H, cyclopentane–H), 1.77–1.80 (s, 4H, cyclopentane–H). ^{13}C NMR (500 MHz, CD_3OCD_3): δ = 22.9 (CH₂, C16/C17, cyclopentane), 29.01 (CH₂, C15/C18, cyclopentane), 55.7 (CH₃, C1/C3, trimethoxybenzyl ring), 78.32 (CH₃, C2, trimethoxybenzyl ring), 106.57 (CH, C7/C9, trimethoxybenzyl ring), 112.24 (C, C14, 1,3-dioxane ring) 114.39 (C, C12, 1,3-dioxane ring), 126.9 (C, C8, trimethoxybenzyl ring), 143.37 (C, C5 trimethoxybenzyl ring), 152.73 (C, C4/C6 trimethoxybenzyl ring), 156.63 (CH, C10, =CH–), 163.72 (C, C11/C13, 1,3-dioxane ring). Evaporation of a solution in petroleum ether/ethyl acetate (2:1 = *v/v*) at room temperature yielded yellow crystals of 8-(3,4,5-trimethoxybenzylidene)-6,10-dioxaspiro[4,5]decane-7,9-dione (**J1**).

A solution of TEAF was prepared dropwise adding triethylamine (40 mL) to methanoic acid (10 mL). A 100 mL round-bottomed flask was charged with 3,4,5-trimethoxybenzaldehyde (0.98 g, 5 mL), 6,10-dioxaspiro[4,5]decane-7,9-dione (0.85 g, 5 mL), TEAF (5 mL), and DMF (5 mL). The mixture was stirred at room temperature for half an hour and was then heated at 50 °C for 12 h. After the mixture was cooled to room temperature and water was added (15 mL), the solution was placed at 5–10 °C for another 16 h. The precipitate was washed twice with ethanol (12 mL) and three times with water and dried. Yield 18.5%. m.p.: 134.9–135.9 °C. Anal. Calcd. For $\text{C}_{18}\text{H}_{22}\text{O}_7$: C, 61.71; H, 6.33. Found: C, 61.63; H, 6.35. ^1H NMR (500 MHz, CD_3OCD_3): 7.14 (s, 2H, Ar-H), 3.22 (s, 2H, –CH₂–), 3.67 (s, 1H, 1,3-dioxane ring–H), 4.27 (s, 9H, –OCH₃), 2.04–2.31 (m, 4H, cyclopentane–H), 1.74–1.82 (s, 4H, cyclopentane–H). ^{13}C NMR (500 MHz, CD_3OCD_3): δ = 22.3 (CH₂, C16/C17, cyclopentane), 23.83 (CH₂, C10, –CH₂–), 28.9 (CH₂, C15/C18, cyclopentane), 49.1 (CH, C12, 1,3-dioxane ring), 55.6 (CH₃, C1/C3,

trimethoxybenzyl ring), 78.3 (CH₃, C2, trimethoxybenzyl ring), 113.72 (C, C14, 1,3-dioxane ring), 115.1 (CH, C7/C9, trimethoxybenzyl ring), 129.7 (C, C8, trimethoxybenzyl ring), 131.94 (C, C5, trimethoxybenzyl ring), 156.7 (C, C4/C6 trimethoxybenzyl ring), 170.12 (C, C11/C13, 1,3-dioxane ring). The evaporation of a solution in petroleum ether/ethyl acetate (4:1 = *v/v*) yielded yellow crystals of 8-(3,4,5-trimethoxybenzyl)-6,10-dioxaspiro[4,5]decane-7,9-dione (**J2**).

2.3. Crystallography

The X-ray data of the two compounds were collected on Rigaku Spider Rapid IP area detector at 293(2) K. The structure of the two compounds was determined by SHELXL-97 and SHELXT-97 [17]. The final cycle of refinement gave $R = 0.0651$ and $wR = 0.1847$ ($R = 0.0578$ and $wR = 0.1682$ for **J2**) with $w = 1/(\sigma^2(F_o^2) + (0.1185P)^2 + 0.1481P)$ ($w = 1/(\sigma^2(F_o^2) + (0.1213P)^2 + 0.0698P)$ for **J2**), where $P = (F_o^2 + 2F_c^2)/3$. The key parameters of **J1** and **J2** are summarized in Table 1. Crystallographic data for the structures reported in this paper have been deposited with the Cambridge Crystallographic Data Centre as supplementary publication No. CCDC-1567472 and CCDC-1567470. Copies of available material can be obtained, free of charge, on application to the Director, CCDC, 12 Union Road, Cambridge CB2 1EZ, UK (Fax: 44-(0)-1223-336033 or e-mail: deposit@ccdc.cam.ac.uk).

Table 1. The key parameters for **J1** and **J2**.

Compounds	J1	J2
Formula	C ₁₈ H ₂₀ O ₇	C ₁₈ H ₂₂ O ₇
CCDC No.	1567472	1567470
Color/shape	red/block	Red/needle
Mr	348.34	350.36
Crystal System, Space group	Triclinic, P-1	Triclinic, P-1
a, b, c (Å)	5.4056(11), 11.465(2), 13.502(3)	8.8778(18), 9.5285(19), 11.082(2)
α, β, γ (°)	92.06(3), 91.35(3), 93.50(3)	89.69(3), 67.38(3), 81.68(3)
Crystal Size (mm)	0.24 × 0.16 × 0.12	0.14 × 0.10 × 0.06
Wavelength (Å)	0.71073	0.71073
θ Ranges (°)	3.02–27.48	3.02–27.48
V(Å ³)	3135.5(2)	854.9(3)
Z	2	2
F(000)	368	372
D/g·cm ^{−3}	1.386	1.361
μ/mm ^{−1}	0.107	0.105
−h, h/−k, k/−l, l	−7:6; −14:14; −17:17	−11:11; −10:12 ; −14:14
Total, unique and [I > 2σ(I)] reflections	8107, 3785, 1786	8389, 3894, 2870
No. of reflections, restraints, parameters	3785, 0, 226	3894, 0, 226
R(int)	0.0312	0.0261
R, wR, S	0.0651, 0.1847, 1.129	0.0578, 0.1682, 1.105
(ΔQ) _{max} , (ΔQ) _{min} (e/Å ³)	0.595, −0.427	0.630, −0.334

3. Results and Discussion

3.1. Crystal Structures

Selected bond lengths and angles of the two compounds are listed in Table 2. The molecular structures of **J1** and **J2** are shown in Figure 1. Packing arrangement in the unit cell of **J1** and **J2** are displayed in Figure 2, respectively.

Table 2. Selected bond lengths (Å) and bond angles (°) of **J1** and **J2**.

	J1	J2
Bond	Dist.	Dist.
C(8)–C(10)	1.445(4)	1.516(2)
C(10)–C(12)	1.359(4)	1.535(2)
C(8)–C(7)	1.407(4)	1.380(3)
C(9)–C(8)	1.394(4)	1.391(2)
O(4)–C(11)	1.206(4)	1.193(2)
O(5)–C(13)	1.197(4)	1.199(2)
Angle	(°)	(°)
C(12)–C(10)–C(8)	137.3(3)	114.13(13)
C(9)–C(8)–C(7)	119.1(3)	119.28(15)
C(9)–C(8)–C(10)	126.7(3)	122.19(15)
C(7)–C(8)–C(10)	114.2(2)	118.51(16)
C(10)–C(12)–C(13)	128.22(15)	109.48(13)
C(10)–C(12)–C(11)	114.83(14)	113.71(15)
C(13)–C(12)–C(11)	116.91(14)	112.53(13)

As can be seen from Figure 1, two compounds both comprise the 3,4,5-trimethoxybenzyl group and the dioxaspiro group. From the bond length data, the C10–C12 bond length of 1.535(2) Å (**J2**) is longer than that of 1.359(4) Å (**J1**), which indicates that the 3,4,5-trimethoxybenzyl group connects with the dioxaspiro group by the central C(10) atoms via double bond (**J1**) and single bond (**J2**), respectively. At the same time, the C8–C10 bond lengths of 1.516(2) Å (**J2**) and 1.445(4) Å (**J1**) are also typical of a C–C single bond. The C(12)–C(10)–C(8) bond angle of 114.13(13)° (**J2**) is smaller than that of 137.3(3)° (**J1**), which is in agreement with similar structures (137.76(2)° and 129.67(2)°) [14]. The double bond lengths of the 1,3-dioxane ring in **J1** (O(4)–C(11) 1.206(4) Å, O(5)–C(13), and 1.197(4) Å) are similar to those of **J2** (O(4)–C(11) 1.193(2) Å, O(5)–C(13), and 1.199(2) Å). In **J1**, the five atoms (C8 and C10–C13) are fairly planar, (plane equation: $-3.0923x - 7.7068y - 5.0336z = 5.6522$), with a maximum deviation from the mean plane of 0.016 Å. However, the five atoms (C8, C10–C13) of **J2** are not planar. The dihedral angle of the plane (C4–C10) and the plane (O4, O6, C11, and C12) is 16.39° (**J1**) and 61.51(9)° (**J2**), respectively.

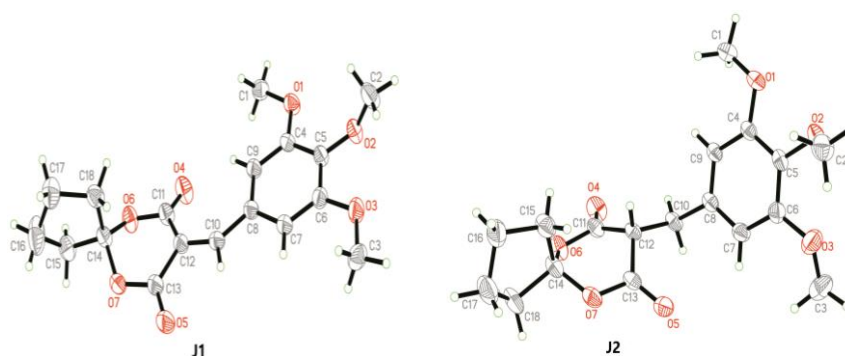
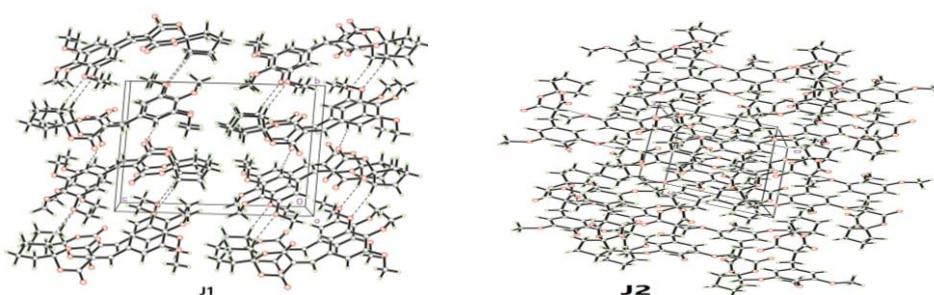
**Figure 1.** The molecular structures of **J1** and **J2** with an atomic numbering scheme.**Figure 2.** Perspective views of three-dimensional packing structures of **J1** and **J2**.

Table 3 shows that the two compounds both comprise some C–H···O intra- and intermolecular hydrogen bonds. The main difference of them is C(9)–H(9A)···O(4) hydrogen bonds. The intramolecular hydrogen bands of **J1** occurs at C(9)–H(9A)···O(4), and the donor and acceptor distances are 2.9287(2) Å. However, the intermolecular hydrogen bands of **J2** occurs at C(9)–H(9A)···O(4), and the donor and acceptor distances are 3.170(2) Å, with symmetry codes $1 - x, -1 - y, 1 - z$, which is in accord with their structures. All above hydrogen bonds generate the three-dimensional network structures of both compounds (Figure 2).

Table 3. Intra- and intermolecular hydrogen bond in **J1** and **J2**.

D–H···A	Symmetry	D–H(Å)	H···A(Å)	D···A(Å)	∠D–H···A (°)
C(2)–H(2B)···O(3) (J1)	intra	0.9600	2.4481	3.0097(2)	117.13
C(9)–H(9A)···O(4) (J1)	intra	0.9300	2.1532	2.9287(2)	140.18
C(10)–H(10A)···O(5) (J1)	intra	0.9300	2.3080	2.7619(2)	109.55
C(1)–H(1A)···O(4) (J1)	$-1 - x, 2 - y, -z$	0.9600	2.5946	3.4547(2)	149.25
C(7)–H(7A)···O(5) (J1)	$1 - x, 1 - y, -z$	0.9300	2.3911	3.3017(3)	166.21
C(18)–H(18B)···O(1) (J1)	$-x, 2 - y, -z$	0.9700	2.5597	3.4643(2)	155.20
C(10)–H(10B)···O(4) (J2)	intra	0.9700	2.4393	2.843(2)	104.60
C(7)–H(7A)···O(5) (J2)	intra	0.9300	2.5840	3.118(2)	116.97
C(2)–H(2B)···O(3) (J2)	intra	0.9599	2.3090	2.929(3)	121.63
C(12)–H(12A)···O(1) (J2)	$1 - x, -y, 1 - z$	0.9804	2.3854	3.300(2)	154.88
C(9)–H(9A)···O(4) (J2)	$1 - x, -1 - y, 1 - z$	0.9299	2.5723	3.170(2)	122.45

3.2. IR Spectra

IR spectra (KBr pellet) of **J1** and **J2** are similar (Figure 3). Weak absorption peaks both can be found at 2956 cm^{−1}, which is due to the stretching vibration C–H of the phenyl ring. Peaks at 1753, 1716, 1255, and 1124 cm^{−1} (**J1**) and 1781, 1753, 1246, and 1124 cm^{−1} (**J2**) are attributed to the stretching vibrations of C=O and C–O bands of the 1,3-dioxane ring. Five absorption peaks in **J1** and four absorption peaks in **J2** can be observed at 1600–1400 cm^{−1}, indicating a C=C stretching vibration of the 3,4,5-trimethoxybenzyl group and the dioxaspiro group by central C(10) atoms via the double bond in **J1**. These are in accordance with the results of the crystal structure analysis.

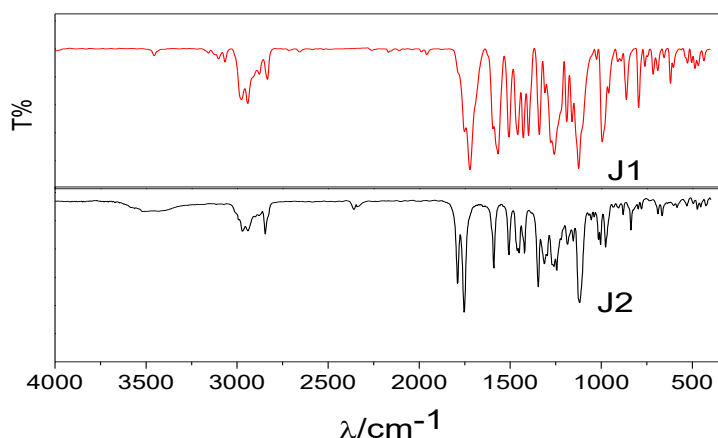


Figure 3. Infrared spectra of **J1** and **J2**.

4. Conclusions

Two new compounds containing 3,4,5-trimethoxybenzyl and 6, 10-dioxaspiro groups, C₁₈H₂₀O₇ (**J1**) and C₁₈H₂₂O₇ (**J2**), have been designed and synthesized via two different routes. Their structures have been determined via single-crystal X-ray diffraction. The crystal structure determinations show that they are both of the triclinic, P-1 space group. The main difference is that the 3,4,5-trimethoxybenzyl group connects with the dioxaspiro group by the central C(10) atoms via double bond in **J1** and via single bond in **J2**, respectively. Both compounds form three-dimensional network structures via C–H···O intra- and intermolecular hydrogen bonds.

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Author Contributions: Jinhe Jiang synthesized Compounds **J1** and **J2**. Xia Wang conceived and designed the experiments. Wulan Zeng wrote the paper.

Conflicts of Interest: The authors confirm that there are no conflicts of interest.

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