



Determination of geometric parameters of the terpenoid 18 α -oleanane by quantum chemistry methods

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ABSTRACT

A comparative study using ab initio calculation (HF/6-31G), semi empirical (PM3) and DFT (B3LYP/6-31G) shows a high correlation with the geometric data of x-ray diffraction of the terpenoid 18 α -oleanane (C₃₂H₅₂O₃), crystallizes in space group C2 with a = 13.3520 (2), b = 6.54000 (10), c = 32.4439(5) Å, V = 2798.13(7) Å³ and Z = 4. The theoretical results were compared to experimental data generated by x-ray diffraction, the difference between the calculated and experimental values is very insignificant. The structure was refined to a final R = 0.027 for the structure factors observed with I \geq 3 σ (I) © 2011 Trade Science Inc. - INDIA

KEYWORDS

PM3;
HF;
DFT;
Oleanane;
X-ray.

INTRODUCTION

A vast series of natural terpenoids are widely distributed in nature and exhibit great structural and biological diversity and are commonly found in vascular plants from various families. They are present at different levels of abundance in all plant parts. Terpenoids are of considerable pharmacological and clinical interest and are used as models for the design of molecules having useful activities (antitumor, antiviral, antibacterial, hepatoprotective, antioxidant, antiulcer and anti-allergen)^[1]. Multidisciplinary efforts of chemist, biochemists and medicinal chemists have led to new developments in the field of terpenoids, which are based primarily on the physical and chemical properties include selective reactivity towards various reagents and the possibilities for functionalization and derivatization

of these natural compounds^[2].

Increasing appropriate methods for the analysis of terpenoids from plant sources have been developed, including: Conventional chromatographic methods, HPLC, LC-NMR, GC-MS which were the most useful and most commonly applied techniques^[3]. Although structural elucidation of terpenoids is not a difficult task, the similarities between the structures can create problems. In particular, the determination of stereochemistry requires NOE/NOESY NMR experiments and/or X-ray analyses. To the best of our knowledge, compared to flavonoids which have been widely investigated^[4-6], there is little published information describing the X-ray crystallography of these kinds of natural terpenoid compounds^[7].

In the continuous of our works to the characterization of natural products^[8-10], the purpose of this study

was to determine which of the quantum chemistry methods PM3, HF, and DFT/B3LYP evaluate more accurately the geometric parameters of the terpenoid 18 α -oleanane.

COMPUTATIONAL DETAILS

All the calculations were carried out using software package Gaussian 98^[11]. Quantum chemical methods at the PM3, DFT and HF level were used to determine the optimal geometry and energies of the terpenoid 18 α -oleanane. In DFT calculations the functional B3LYP was used with standard Pople's split valence 6-31G(d,p) basis set^[12]. Such combination is being used with good results for organic hydrogen-bonded systems^[13,14]. It represents a good compromise between economy of computational resources, accuracy and applicability to many-atoms molecules. The 6-31G(d,p) basis set was used in the HF calculations. The optimized geometries were characterized as true minima on the potential energy surface (PES) since all harmonic frequencies were real. Ab initio geometry optimization on 18 α -oleanane (C₃₂H₅₂O₃) was performed starting from the geometry found in the X-ray refinement.

RESULTS AND DISCUSSION

We present in this study a theoretical determination of the geometric parameters of 18 α -oleanane by semi-empirical PM3^[15], ab initio HF^[16] and DFT levels^[17] by using the functional B3LYP^[12]. This procedure has been efficiently employed in the structural determination of diterpenoids^[18] and other organic compounds^[19,20].

The studied terpenoid 19 β ,28-epoxy-18 α oleanane (C₃₂H₅₂O₃) (**2**) is selectively prepared by Salvador et al^[2] under Wagner-Meerwein rearrangement of lupane terpenoid (Betulin- 3 β -yl acetate) (**1**) by using bismuth(III) salts (Bi(OTf)₃·xH₂O) as catalysts in refluxing CH₂Cl₂ (Figure 1). The physical data (IR, MS, NMR and X-ray crystallography) of obtained compounds were indicated^[2]. So, we have used the experimental X-ray diffraction data in our theoretical approach.

The displacement ellipsoid plot with the numbering scheme for the 18 α -oleanane (**2**) is shown in (Figure 2). Selected X-ray diffraction data summarize bond lengths, bond angles and torsion angles in TABLES 1, 2 and 3 respectively.

In order to establish the accuracy of HF/6-

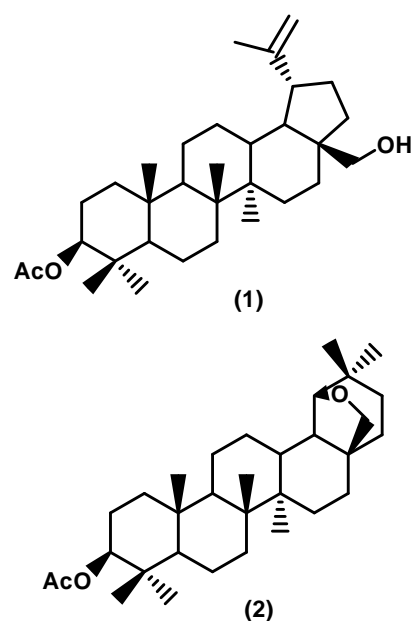


Figure 1 : Structure of lupane terpenoid **1** and 18 α -oleanane **2** derivatives

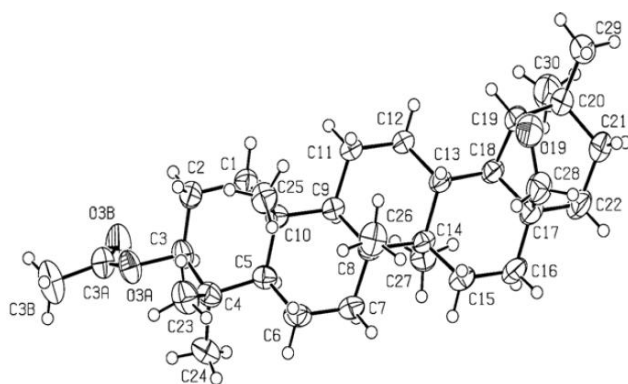


Figure 2 : Perspective view of the molecule (**2**) showing the atom-labelling scheme. Displacement ellipsoids are drawn at the (50% probability level, H atoms of arbitrary sizes).

31G(d,p), PM3 and B3LYP/6-31G(d,p) models chemistry in the reproducibility of structural properties of the 18 α -oleanane (**2**), the computational data were compared with the experimental data taken from literature^[2]. The computational data are generated for the gas phase and compared with the solid state ones because the only experimental data found in the literature were from an X-ray study.

Molecules optimized with B3LYP/6-31G(d,p) model indicating that molecule (**2**) is into his minimum values of energy. The results in TABLES 1 and 2 revealed a general similitude between theoretically and experimentally calculated bond distances and bond angles for 18 α -oleanane (**2**). The theoretical and experimental C-

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TABLE 1 : Bond lengths [Å°] for the simulated 18 α -oleanane (C₃₂H₅₂O₃), compared with x-ray data taken from ref^[2].

Bond lengths	X-ray	HF/6-31G**	Error %	B3LYP/6-31G**	Error%	PM3	Error%
C1 C2	1.533(3)	1.52964	0.26	1.53463	0.08	1.51719	1.05
C2 C3	1.505(3)	1.51851	0.87	1.52406	1.24	1.53414	1.91
C3A C3B	1.496(3)	1.50461	0.55	1.51126	0.99	1.50405	0.51
C4 C23	1.536(3)	1.53949	0.20	1.54302	0.43	1.52585	0.68
C4 C5	1.556(3)	1.56618	0.62	1.57193	1.00	1.55461	0.10
C5 C10	1.557(3)	1.56414	0.43	1.57071	0.86	1.54973	0.48
C8 C26	1.545(3)	1.54798	0.16	1.55103	0.36	1.53244	0.83
C8 C9	1.569(2)	1.57256	0.21	1.57832	0.57	1.55637	0.82
C8 C14	1.587(3)	1.60426	1.06	1.61279	1.600	1.57744	0.62
C14 C27	1.540(3)	1.55151	0.72	1.55349	0.85	1.53192	0.54
C17 C28	1.524(3)	1.53913	0.97	1.54619	1.43	1.54736	1.50
C19 C20	1.546(3)	1.54627	0.00	1.55598	0.62	1.55755	0.72
C20 C29	1.526(4)	1.53575	0.60	1.53957	0.85	1.52795	0.09
C20 C21	1.531(3)	1.54681	1.01	1.55364	1.46	1.54231	0.71
C3O3A	1.463(2)	1.43322	2.05	1.45659	0.46	1.43689	1.804
O3A C3A	1.330(3)	1.32500	0.39	1.35349	1.73	1.36374	2.51
C3A O3B	1.197(3)	1.18921	0.67	1.21230	1.25	1.21568	1.52
C19 O19	1.438(3)	1.41768	1.43	1.44337	0.34	1.43596	0.16
O19 C28	1.432(3)	1.41007	1.55	1.43485	0.17	1.43110	0.08
C1 H1A	0.9700	1.08417	11.76	1.09482	12.86	1.11233	14.67
C3 H3	0.9800	1.08234	10.43	1.09551	11.78	1.11954	14.23
C24 H24A	0.9600	1.08186	12.68	1.09354	13.90	1.09739	14.30
C5 H5	0.9800	1.09129	11.34	1.10278	12.52	1.12417	14.70
C9 H9	0.9800	1.08428	10.63	1.09744	11.97	1.12740	15.04
C12 H12A	0.9700	1.08545	11.89	1.09599	12.97	1.10725	14.14
C13 H13	0.9800	1.08504	10.71	1.09680	11.91	1.12477	14.76
C27 H27A	0.9600	1.08104	12.60	1.09175	13.71	1.10162	14.75
C30 H30A	0.9600	1.08381	12.89	1.09361	13.91	1.10251	14.84
C28 H28A	0.9700	1.08417	11.76	1.09691	13.08	1.10481	13.89

TABLE 2 : Bond angles [°] for the simulated 18 α -oleanane (C₃₂H₅₂O₃), compared with x-ray data taken from ref^[2].

Bond angles	X-ray	HF/6-31G**	Error%	B3LYP/6-31G**	Error%	PM3	Error%
C2 C1 C10	113.04(15)	113.88532	0.74	113.74956	0.62	110.81220	1.97
C3 C2 C1	110.15(15)	111.57127	1.28	111.19503	0.94	109.48833	0.60
C3 C4 C23	111.56(17)	111.84748	0.25	111.79507	0.20	110.77040	0.70
C23 C4 C24	108.49(17)	107.17171	1.23	107.50357	0.91	108.63274	0.12
C3 C4 C5	106.69(14)	106.36907	0.30	106.41392	0.26	106.82162	0.12
C6 C5 C4	113.41(15)	114.60128	1.04	114.46517	0.92	113.57345	0.14
C4 C5 C10	117.90(15)	117.51600	0.32	117.45202	0.33	115.68533	1.87
C7 C6 C5	110.56(16)	110.50219	0.05	110.62825	0.06	109.74763	0.73
C6 C7 C8	113.69(17)	114.20655	0.45	114.15842	0.41	111.21777	2.17
C26 C8 C7	107.33(19)	106.93246	0.37	107.12642	0.19	107.82816	0.46
C7 C8 C9	108.43(15)	108.26870	0.15	108.50358	0.06	109.33280	0.83
C8 C9 C10	116.77(14)	117.47856	0.60	117.28589	0.44	115.52603	1.06

Bond angles	X-ray	HF/6-31G**	Error%	B3LYP/6-31G**	Error%	PM3	Error%
C25 C10 C1	107.13(16)	107.39615	0.24	107.67072	0.50	108.64580	1.41
C27 C14 C15	106.80(18)	106.81816	0.01	107.10718	0.28	108.52058	1.60
C15 C14 C8	111.36(16)	111.29607	0.05	111.21781	0.12	110.65427	0.63
C13 C18 C17	113.94(16)	114.16598	0.19	114.35243	0.36	114.48260	0.47
C29 C20 C21	108.8(2)	109.29300	0.43	109.31144	0.45	109.15830	0.31
C21 C22 C17	112.81(18)	112.86340	0.04	112.81594	0.00	113.04737	0.20
O19 C28 C17	106.5(2)	106.01939	0.47	106.51770	0.00	106.98700	0.43
O3A C3 C2	109.77(15)	109.35649	0.37	109.53822	0.21	109.55500	0.19
O3A C3 C4	107.14(14)	108.30564	1.08	108.20797	0.99	107.55479	0.38
O3A C3 H3	108.2	107.58958	0.56	107.14403	0.97	110.38835	2.02
C3A O3A C3	118.74(16)	119.23973	0.41	117.36475	1.15	119.73322	0.83
O3B C3AO3A	123.89(19)	124.20452	0.25	124.29414	0.32	120.71556	2.56
O3B C3AC3B	124.5(2)	124.58072	0.04	125.10138	0.46	127.14129	2.10
C29 C20 C21	108.8(2)	109.29300	0.43	109.31144	0.45	109.15830	0.31

TABLE 3 : Torsion angles [°] for the simulated 18 α -oleanane (C₃₂H₅₂O₃), compared with x-ray data taken from ref^[2].

Torsion angles	X-ray	HF/6-31G**	Error%	B3LYP/6-31G**	Error%	PM3	Error%
C10 C1 C2 C3	-58.0(2)	-55.20295	4.85	-55.84187	3.75	-62.81247	8.25
C1 C2 C3 C4	58.0(2)	56.83759	2.03	57.10729	1.58	63.13292	8.80
C2 C3 C4 C23	72.9(2)	72.49876	0.58	72.20640	0.98	67.37180	7.61
C3 C4 C5 C6	-177.24(18)	-173.81807	1.93	-174.53532	1.52	-178.93151	0.95
C23 C4C5C10	-72.7(2)	-70.70069	2.77	-70.98060	2.39	-68.26320	6.13
C4 C5 C6 C7	162.17(18)	161.52070	0.40	161.80457	0.22	163.54149	0.84
C10 C5 C6 C7	-62.7(2)	-62.73089	0.01	-62.63138	0.14	-65.96454	5.16
C5 C6 C7 C8	58.3(3)	58.60312	0.46	58.24794	0.15	62.13529	6.51
C4 C5 C10 C25	66.3(2)	66.26531	0.09	66.66210	0.51	66.14255	0.27
C12 C13 C14 C27	65.0(2)	66.57046	2.38	65.68780	1.01	60.07306	7.73
C27 C14 C15 C16	61.4(2)	60.81349	0.99	61.28786	0.22	61.19647	0.37
C8 C14 C15 C16	-176.82(19)	-177.63025	0.45	-177.08599	0.14	-177.62846	0.45
C15 C16 C17 C18	-45.9(3)	-43.84531	4.55	-44.29081	3.57	-46.69778	1.65
C12 C13 C18 C19	72.2(2)	71.47184	1.03	71.30680	1.27	77.02715	6.64
C16 C17 C22 C21	-174.1(2)	-173.43194	0.39	-173.59319	0.30	-175.98346	1.06
C28 C17 C22 C21	-47.6(3)	-47.45044	0.37	-47.29925	0.71	-49.61850	4.15
C18 C17 C22 C21	61.1(3)	60.90315	0.37	61.12906	0.01	60.05037	1.76
C2 C3 O3A C3A	92.0(2)	84.92607	7.70	85.36260	7.23	90.14941	2.04
C4 C3 O3A C3A	-142.38(19)	-149.99579	5.34	-149.21740	4.80	-149.49429	4.99
C3 O3A C3A C3B	174.8(2)	179.90729	2.90	179.77083	2.83	178.91010	2.33
O3A C3 C4 C23	-49.5(2)	-49.63466	0.22	-50.24512	1.45	-52.27299	5.55
O3A C3 C4 C24	69.2(2)	67.50774	2.48	67.27607	2.81	67.37379	2.67
O3A C3 C4 C5	-174.95(16)	-175.72474	0.44	-175.85331	0.51	-176.19862	0.71
C1 C2 C3 O3A	178.98(17)	178.39401	0.32	178.83354	0.08	-178.43160	0.30
O19 C19 C20 C29	-63.9(2)	-63.09122	1.29	-62.31185	2.51	-63.43493	0.76
O19 C19 C20 C21	54.0(2)	55.52818	2.77	56.15222	3.94	56.61896	4.79
C18 C19 C20 C21	-61.8(3)	-59.63100	3.68	-59.40388	3.93	-59.07090	4.46
O19 C19 C20 C30	175.4(2)	177.91034	1.41	178.44430	1.72	177.99157	1.46
C16 C17 C28 O19	-150.38(16)	-150.69526	0.20	-149.80710	0.38	-148.42409	1.30
C22 C17 C28 O19	84.7(2)	84.41106	0.36	84.99180	0.31	87.19798	2.91
C18 C17 C28 O19	-29.0(2)	-28.60485	1.44	-28.04899	1.44	-25.72492	12.68

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C and C–O bond distances present small differences ; using HF/6-31G(d,p) method data is in the order of 0.00–0.03 Å°, in the order of 0.001–0.02 Å° by using DFT/B3LYP/6-31G(d,p) method data and in the order of 0.001–0.03 Å° by using PM3 method data, while the C–H bond distances show noticeable differences using the three methods of calculation, respectively are in the range of 0.102–0.127 Å°, 0.115–0.136 Å° and 0.130–0.148 Å°. The large differences in the solid state can be attributed to the fact that C–H groups constituted the site for the intermolecular interactions and hydrogen bonds with the water of the crystal lattice. Oppositely, in the simulation is modeled a single molecule free of intermolecular interactions, therefore the bond distances are almost not modified.

The theoretical and experimental bond angles between carbon atoms present a differences about 0.02° to 1.92° by using HF/6-31G(d,p), about 0.00° to 2.55° by using B3LYP/6-31G(d,p) and around of 0.03° to 4.44° by using PM3, when we whereas the PM3 method overestimates the angle alpha . The presence of an oxygen atom diverted the experimental values around 0.4–1.6° with respect to the theoretical bond angle, such as the bond distances. The standard deviations for bond distances and bond angles of the molecule are small, (TABLES 1, 2), thus the B3LYP/6-31G(d,p) method give a good agreement between theoretical and experimental data. Finally, the torsion angles (TABLE 3), regularly utilized to define the molecular planarity, their values tended to be 0° or 180°. The presence of oxygen atom originates a great deviation of the angle in a range of 4–8°. The differences observed between the theoretical and experimental results are probably due to packing effects and in another hand the theoretical calculations imply isolated molecules in gaseous phase state while experimental results refer to molecules in the solid state.

CONCLUSION

We have tested the PM3, HF and DFT methods to determine geometric parameters of the terpenoid 18a-oleanane. DFT/B3LYP/6-31G(d,p) model chemistry can be considered as the most appropriate method to facilitate the reproducibility of structural properties, because the bond distances, bond angles and torsion angles of the simulated molecules are generally adjusted to the experimental conformations into a strict range of variation . Calculated geometric parameters represent a good ap-

proximation and can provide a starting point to calculate other parameters, such as vibrational wavenumbers.

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