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## Key indicators

Single-crystal X-ray study
$T=100 \mathrm{~K}$
Mean $\sigma(\mathrm{C}-\mathrm{C})=0.002 \AA$
$R$ factor $=0.025$
$w R$ factor $=0.066$
Data-to-parameter ratio $=9.2$

For details of how these key indicators were automatically derived from the article, see http://journals.iucr.org/e.
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## (-)-Isosantonic acid: alteration of the hydrogenbonding mode by configurational inversion at a single centre in a $\gamma, \varepsilon$-diketocarboxylic acid

The title diketo acid, ( $1 R, 3 \mathrm{a} S, 6 \mathrm{a} S, 7 R, 9 S)-(-)-\alpha, 3 \mathrm{a}, 7-$ trimethyl-5,8-dioxo-1,4-ethanoperhydropentalene-1-acetic acid $\left(\mathrm{C}_{15} \mathrm{H}_{20} \mathrm{O}_{4}\right)$, is shown to aggregate in the crystal structure as acid-to-ketone hydrogen-bonding catemers, whose chains follow $2_{1}$ screw axes from each carboxyl to a ketone in a neighbouring molecule $[\mathrm{O} \cdots \mathrm{O}=2.7472$ (13) $\AA$ and $\mathrm{O} \cdots \mathrm{H}-$ $\left.\mathrm{O}=172.7(17)^{\circ}\right]$. Two parallel counterdirectional screwrelated single-strand hydrogen-bonding chains pass through the cell in the a direction. Six intermolecular $\mathrm{C}-\mathrm{H} \cdots \mathrm{O}=\mathrm{C}$ close contacts are found. Comparisons are drawn with a diastereomer having the opposite configuration at the methylated chiral centre adjacent to the carboxyl group.

## Comment

Transformations of (-)- $\alpha$-santonin, a sesquiterpenoid Artemisia isolate, offer a rich vein of chiral non-racemic keto acids (Brunskill et al., 1999, 2001, 2002; Thompson \& Lalancette, 2003). Several such compounds provide opportunities to examine hydrogen-bonding changes due to inversion at a single chiral centre.

(I)

The title compound, (I), is a tricyclic diketo acid having the absolute $S$ configuration at C 9 , whose chirality is independent of the tricyclic framework. Compound (I) is thus the C9diastereomer of (-)-parasantonic acid, (II) (Zinczuk et al., 2004).

Fig. 1 shows the asymmetric unit of (I) and its numbering. The rigidity of the system leaves significant rotations around only $\mathrm{C} 1-\mathrm{C} 9$ and $\mathrm{C} 9-\mathrm{C} 10$. The arrangement about $\mathrm{C} 1-\mathrm{C} 9$ is staggered, with the carboxyl and $\gamma$-ketone (O1) anti to one another [torsion angle $\mathrm{C} 8-\mathrm{C} 1-\mathrm{C} 9-\mathrm{C} 10=166.09(10)^{\circ}$ ]. The carboxyl is rotated to give a $\mathrm{C} 1-\mathrm{C} 9-\mathrm{C} 10-\mathrm{O} 3$ torsion angle of $79.95(15)^{\circ}$. This arrangement of the carboxyl relative to the tricyclic framework differs markedly from that in the C9diastereomer, ( - )-parasantonic acid, (II), where these angles are -50.7 (5) and 146.0 (4) ${ }^{\circ}$, respectively (Fig. 2). In (II), the carboxyl and $\gamma$-ketone carbonyls are roughly parallel [torsion angle $\left.\mathrm{O} 1-\mathrm{C} 8 \cdots \mathrm{C} 10-\mathrm{O} 3=28.1(5)^{\circ}\right]$, but in (I) they point

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Figure 1
The molecular structure of (I), showing displacement ellipsoids drawn at the $50 \%$ probability level.


Figure 2
The molecular structure of ( - )-parasantonic acid, (II), which differs from (I) only in the configuration around C9.
away from one another [torsion angle $\mathrm{O} 1-\mathrm{C} 8 \cdots \mathrm{C} 10-\mathrm{O} 3=$ $-126.05(12)^{\circ}$ ], a difference of more than $150^{\circ}$. The observed $\mathrm{C} 1-\mathrm{C} 9$ conformations for (I) and (II) both position atom $\mathrm{H} 9 A$ where it is bracketed by atoms C6a and C8, and presumably minimize torsional crowding. The resulting change in the angular arrangement of the carboxyl has dramatic consequences for the packing of (I) versus (II) (see below). As (I) is not dimeric, disorder-averaging of carboxyl bond lengths and angles is absent, and these values (Table 1) resemble those in highly ordered dimeric carboxyls.

Fig. 3 illustrates the packing of (I), involving acid-to-ketone catemers, whose hydrogen-bonding follows a $2_{1}$ screw from each carboxyl to the $\gamma$-ketone (O1) in a neighbour [ $\mathrm{O} \cdots \mathrm{O}=$ 2.7472 (13) $\AA$ and $\left.\mathrm{O}-\mathrm{H} \cdots \mathrm{O}=172.7(17)^{\circ}\right]$. Two parallel counterdirectional chains pass through the cell along the $a$ axis. This mode predominates among chiral non-racemic keto acids, but differs from the rare acid-to-acid hydrogen bonding found in (II). This change results specifically from the inversion at C 9 and the extension of $\mathrm{O} 4-\mathrm{H} 4$ at a markedly altered


Figure 3
A partial packing diagram for (I), illustrating the two parallel counterdirectional screw-related single-strand hydrogen-bonded (dashed lines) chains passing through the cell in the $a$-axis direction. Displacement ellipsoids are drawn at the $40 \%$ probability level. H atoms not involved in hydrogen bonding have been omitted.
angle relative to the remainder of the molecule in (I) compared with (II).

We characterize the geometry of hydrogen bonding to carbonyls using a combination of $\mathrm{H} \cdots \mathrm{O}=\mathrm{C}$ angle and $\mathrm{H} \cdots \mathrm{O}=\mathrm{C}-\mathrm{C}$ torsion angle. In (I), these two angles are 137.7 (5) and $-20.1(8)^{\circ}$, respectively.

Compound (I) has six intermolecular $\mathrm{C}=\mathrm{O} \cdots \mathrm{H}-\mathrm{C}$ close contacts (Table 2).

## Experimental

Based on a procedure of Francesconi (1895), (-)-santonic acid, derived from (-)- $\alpha$-santonin of known absolute stereochemistry, was refluxed in acetic acid for 18 h . The solution was then concentrated and heated for 4 h in vacuo at 448 K , yielding about $10 \%$ of the enol lactone of (I) after work-up. Brief acidic hydrolysis then gave (I) (m.p. 424 K ), which was recrystallized from diisopropyl ether. Optical-rotation data for (I) were reported by Francesconi (1895). The solid-state ( KBr ) IR spectrum of (I) has a $\mathrm{C}=\mathrm{O}$ absorption at $1747 \mathrm{~cm}^{-1}$ (strained $\varepsilon$-ketone), as well as bands at 1730 and $1685 \mathrm{~cm}^{-1}$ for, respectively, the carboxyl $\mathrm{C}=\mathrm{O}$ lacking hydrogen bonding and the hydrogen-bonded $\gamma$-ketone. In $\mathrm{CHCl}_{3}$ solution, where dimers predominate, the $\varepsilon$-ketone appears at $1741 \mathrm{~cm}^{-1}$, with a single peak at $1709 \mathrm{~cm}^{-1}$ for the 'normal' absorptions of both the acid and $\gamma$-ketone.

## Crystal data

$\mathrm{C}_{15} \mathrm{H}_{20} \mathrm{O}_{4}$
$M_{r}=264.31$
Orthorhombic, $P 2_{1} 2_{1} 2_{1}$
$a=8.3801(2) \AA$
$b=12.5398(2) \AA$
$c=12.6852(2) \AA$
$V=1333.02(4) \AA$

$$
\begin{aligned}
& Z=4 \\
& D_{x}=1.317 \mathrm{Mg} \mathrm{~m}^{-3} \\
& \mathrm{Cu} \mathrm{~K} \mathrm{\alpha} \text { radiation } \\
& \mu=0.77 \mathrm{~mm}^{-1} \\
& T=100(2) \mathrm{K} \\
& \text { Parallelepiped, colourless } \\
& 0.50 \times 0.34 \times 0.26 \mathrm{~mm}
\end{aligned}
$$

## Data collection

Bruker SMART CCD area-detector diffractometer
$\varphi$ and $\omega$ scans
Absorption correction: multi-scan
(SADABS; Blessing, 1995)
$T_{\text {min }}=0.750, T_{\text {max }}=0.820$

## Refinement

| Refinement on $F^{2}$ | $(\Delta / \sigma)_{\text {max }}<0.001$ |
| :---: | :---: |
| $R\left[F^{2}>2 \sigma\left(F^{2}\right)\right]=0.025$ | $\Delta \rho_{\text {max }}=0.21 \mathrm{e}^{\text {® }}{ }^{-3}$ |
| $w R\left(F^{2}\right)=0.066$ | $\Delta \rho_{\text {min }}=-0.16$ e $\AA^{-3}$ |
| $S=0.98$ | Extinction correction: SHELXL97 |
| 2321 reflections | (Sheldrick, 1997) |
| 253 parameters | Extinction coefficient: 0.0065 (5) |
| H -atom parameters constrained $w=1 /\left[\sigma^{2}\left(F_{\mathrm{o}}^{2}\right)+(0.0435 P)^{2}\right.$ | Absolute structure: Flack (1983), with 950 Friedel pairs |
| + $0.3883 P$ ] | Flack parameter: 0.02 (15) |

Table 1
Selected bond lengths ( $\AA$ ).

| $\mathrm{O} 3-\mathrm{C} 10$ | $1.2098(15)$ | $\mathrm{O} 3-\mathrm{C} 10$ | $1.2098(15)$ |
| :--- | :--- | :--- | :--- |
| $\mathrm{O} 3-\mathrm{C} 10-\mathrm{C} 9$ | $124.96(11)$ | $\mathrm{O} 4-\mathrm{C} 10-\mathrm{C} 9$ | $112.21(11)$ |

Table 2
Hydrogen-bond geometry ( $\AA$, ${ }^{\circ}$ ).

| $D-\mathrm{H} \cdots A$ | D-H | $\mathrm{H} \cdots A$ | $D \cdots A$ | $D-\mathrm{H} \cdots A$ |
| :---: | :---: | :---: | :---: | :---: |
| $\mathrm{O} 4-\mathrm{H} 4 \cdots \mathrm{O} 1^{\text {i }}$ | 0.847 (19) | 1.90 (2) | 2.7472 (13) | 172,7 (17) |
| $\mathrm{C} 11-\mathrm{H} 11 B \cdots \mathrm{O} 2^{\text {ii }}$ | 0.991 (17) | 2.650 (16) | 3.1916 (17) | 114.5 (11) |
| $\mathrm{C} 3-\mathrm{H} 3 A \cdots \mathrm{O} 3^{\text {iii }}$ | 1.001 (15) | 2.666 (15) | 3.6268 (16) | 161.1 (12) |
| $\mathrm{C} 6-\mathrm{H} 6 A \cdots \mathrm{O}^{\text {iv }}$ | 0.945 (18) | 2.652 (18) | 3.5891 (17) | 171.4 (14) |
| $\mathrm{C} 7-\mathrm{H} 7 A \cdots \mathrm{O} 3^{\text {iii }}$ | 0.979 (18) | 2.519 (18) | 3.4278 (16) | 154.3 (13) |
| $\mathrm{C} 9-\mathrm{H} 94 \cdots \mathrm{O} 3^{\text {iv }}$ | 0.960 (15) | 2.542 (16) | 3.4964 (15) | 172.6 (11) |
| $\mathrm{C} 9-\mathrm{H} 94 \cdots \mathrm{O} 4^{\text {iv }}$ | 0.960 (15) | 2.669 (15) | 3.3816 (16) | 131.3 (11) |

Symmetry codes: (i) $x-\frac{1}{2},-y+\frac{1}{2},-z+1$; (ii) $-x+2, y+\frac{1}{2},-z+\frac{3}{2}$; (iii) $-x+\frac{3}{2},-y+1, z+\frac{1}{2}$; (iv) $x+\frac{1}{2},-y+\frac{1}{2},-z+1$.

15403 measured reflections 2321 independent reflections 2320 reflections with $I>2 \sigma(I)$
$R_{\text {int }}=0.017$
$\theta_{\text {max }}=69.2^{\circ}$
$(\Delta / \sigma)_{\max }<0.001$
$\Delta \rho_{\text {max }}=0.21 \mathrm{e}^{\AA^{-3}}$
Extinction correction: SHELXL97 (Sheldrick, 1997)
Extinction coefficient: 0.0065 (5)
Absolute structure: Flack (1983),
Flack parameter: 0.02 (15)

All H atoms were found in electron-density difference maps, placed in calculated positions and allowed to refine freely, both positionally and isotropically.

Data collection: SMART (Bruker, 2000); cell refinement: SAINTPlus (Bruker, 2000); data reduction: SAINT-Plus; program(s) used to solve structure: SHELXS97 (Sheldrick, 1997); program(s) used to refine structure: SHELXL97 (Sheldrick, 1997); molecular graphics: SHELXTL (Bruker, 2000); software used to prepare material for publication: SHELXTL.

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