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Ammonium quercetin-5′-sulfonate formamide solvate

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Key indicators

Single-crystal X-ray study
T = 293 K
Mean σ(C–C) = 0.005 Å
R factor = 0.049
wR factor = 0.142
Data-to-parameter ratio = 12.6

For details of how these key indicators were automatically derived from the article, see http://journals.iucr.org/e.

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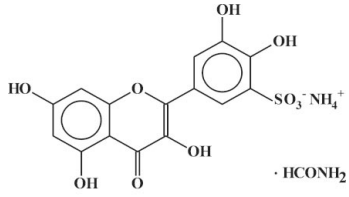
The ammonium salt of 2,3-dihydroxy-5-(3,5,7-trihydroxy-4-oxo-4*H*-1-benzopyran-2-yl)benzenesulfonic acid (common name quercetin-5′-sulfonate), $NH_4^+\cdot C_{15}H_9O_{10}S^-\cdot CH_3NO$, crystallizes as the formamide solvate. The presence of the sulfonate group on the flavonoid core increases the solubility of this compound in water. In the solid state, anion–anion, anion–cation and anion–solvent–cation assemblies are formed by numerous intermolecular hydrogen bonds.

Comment

The natural and biologically active polyphenolic compound quercetin (Geissmann, 1962; Florkin & Stotz, 1968; Garrett & Grisham, 1999) is one of the best known flavonoids and is the most frequently examined. It is widely distributed in plants, especially in flowers, rinds and barks. Quercetin and its glycosides exhibit a wide range of biological activities (Formica & Regelson, 1997; Robak & Gryglewski, 1996; Hollman & Katan, 1999); they are components of pharmaceuticals and are applied in therapy (*e.g.* rutin, troxerutin, diosmin; Budavari *et al.*, 1996). Quercetin is used as a yellow dye (Jin *et al.*, 1990) and it is also used in chemical analysis for spectrophotometric and spectrofluorimetric estimations of metals (Jerzmanowska, 1973; Kopacz, 2003).

Quercetin and other flavonoids form metal complexes which exhibit stronger physiological activity. However, simple flavonoids and their complexes are hardly soluble in water, which limits their applications. Much better solubility in water is shown by some sulfonic derivatives of flavonoids and, at the same time, these retain the properties of the parent compound (Heneczkowski *et al.*, 2001).

To date, no crystal structure of any sulfonic derivative of flavonoids has been reported. In order to examine the conformational properties and crystal structure of quercetin sulfonate, we have synthesized and determined the structure of the title formamide solvate of ammonium quercetin-5′-sulfonate (NH_4QSA·$HCONH_2$), (I).



(I)

The parent flavone core of the anion of (I) (Fig. 1, Table 1) is similar to that observed in quercetin dihydrate (Jin *et al.*, 1990) and other quercetin derivatives reported in the Cambridge Structural Database (CSD, Version 5.25; Allen,

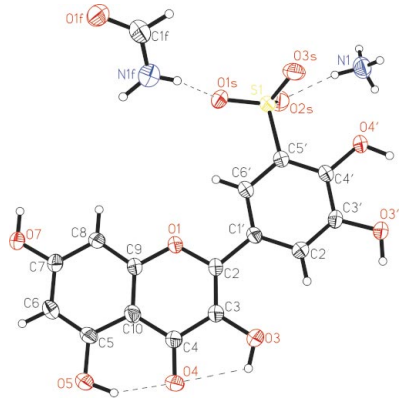


Figure 1
A perspective view of (I). Displacement ellipsoids are drawn at the 50% probability level. Dashed lines indicate hydrogen bonds.

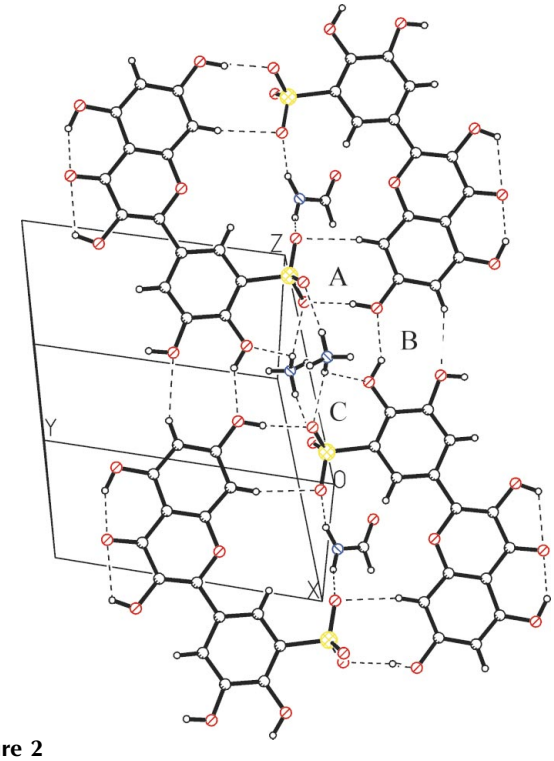


Figure 2
The molecular arrangement of (I), projected on to the (101) plane. Dashed lines indicate hydrogen bonds.

2002; CSD refcodes ARTEMT, DETSUQ, EDAXUC, FEFBEX, FORHID, HIQKEX, OFOGAR, PILCIW, SAZBIE, TIJZIV and VAWWIZ). The intramolecular O3—H3···O4···H5—O5 hydrogen-bond system is also typical for this group of derivatives (Jin *et al.*, 1990). Moreover, the benzopyran and benzene rings are coplanar; the O1—C2—C1′—C2′ torsion angle is −176.1 (3)°. Intramolecular C6′—H6′···O1 and C2′—H2′···O3 interactions (Table 2) play a significant role in stabilizing the planarity of the system. In contrast with the conformation of quercetin itself, a *transoid* orientation of the O3′ hydroxyl and pyran O1 atoms is observed in (I).

The chemical components of (I) are bonded by numerous intermolecular hydrogen bonds (Table 2), which form anion–anion, anion–cation and anion–solvent–cation patterns. Two cyclic patterns, *A* and *B* (Fig. 2), described by graph sets $R_2^2(8)$ and $R_2^2(9)$ (Etter *et al.*, 1990), respectively, link three neighbouring anions through the sulfate, hydroxyl and C—H groups. The tapes of anions extending along the (101) plane are interconnected by cations and formamide molecules. The anions of adjacent tapes related by inversion centres form stacks of aromatic rings. The interplanar distance between benzopyran fragments about the centre of symmetry at $(\frac{1}{2}, \frac{1}{2}, 0)$ is 3.34 (1) Å, while that about $(1, \frac{1}{2}, 0)$ is 3.24 (1) Å.

The cyclic pattern *C* [graph-set motif $R_1^2(6)$; Fig. 2] is formed by the cation–anion pair involving the ammonium atom H2n chelated by the sulfate and hydroxyl O atoms. The cation is also engaged in the formation of hydrogen bonds with two other anions, giving cyclic patterns $R_6^6(12)$ and $R_4^4(12)$ about the centre of symmetry at $(0, 0, \frac{1}{2})$.

Strong bonding of the solvent molecule through five hydrogen bonds is observed in (I). The amino H atoms are linked to two sulfate O1s atoms, and the resulting patterns are asymmetric, $R_3^2(14)$, and centrosymmetric, $R_4^2(8)$. C1f—H1f···O5 is the third solvent···anion interaction, while atom O1f acts as a double acceptor of the cation H—N1 and anion H—O3′ moieties.

Experimental

The title solvate was obtained by recrystallization of quercetin-5′-sulfonate (Terpilowski *et al.*, 1970) from a formamide solution containing ammonia. Well shaped prismatic orange crystals of (I) were obtained after six months by slow evaporation of formamide at room temperature. Desolvation of the crystal was observed in the temperature range 498–503 K, while the melting point determined on a Boetius microscope was 515–523 K (decomposition).

Crystal data

$H_4N^+\cdot C_{15}H_9O_{10}S^-\cdot CH_3NO$
M_r = 444.37
Triclinic, $P\overline{1}$
a = 7.878 (2) Å
b = 10.584 (4) Å
c = 11.184 (4) Å
α = 68.25 (3)°
β = 86.54 (2)°
γ = 84.40 (2)°
V = 861.7 (5) Å^3
Z = 2
D_x = 1.713 Mg m^{-3}
Cu $K\alpha$ radiation
Cell parameters from 40 reflections
θ = 6–19°
μ = 2.35 mm^{-1}
T = 293 (2) K
Needle, orange
0.41 × 0.11 × 0.09 mm

Data collection

Kuma KM4 four-circle diffractometer
$\omega/2\theta$ scans
Absorption correction: cylindrical (*KM-4 Software*; Kuma Diffraction, 1991)
T_{min} = 0.78, T_{max} = 0.81
3838 measured reflections
3666 independent reflections
1957 reflections with $I > 2\sigma(I)$
R_{int} = 0.038
θ_{max} = 80.3°
$h = -10 \rightarrow 10$
$k = -12 \rightarrow 13$
$l = 0 \rightarrow 13$
3 standard reflections
every 100 reflections
intensity decay: 1.3%

Refinement

Refinement on F^2
$R[F^2 > 2\sigma(F^2)]$ = 0.049
$wR(F^2)$ = 0.143
S = 1.00
3666 reflections
290 parameters
H atoms treated by a mixture of independent and constrained refinement
$w = 1/[\sigma^2(F_o^2) + (0.0846P)^2]$ where $P = (F_o^2 + 2F_c^2)/3$
$(\Delta/\sigma)_{max} < 0.001$
$\Delta\rho_{max}$ = 0.42 e Å^{-3}
$\Delta\rho_{min}$ = −0.42 e Å^{-3}
Extinction correction: *SHELXL97* (Sheldrick, 1997)
Extinction coefficient: 0.0048 (9)

Table 1
Selected geometric parameters (Å, °).

O1—C9	1.359 (3)	C7—O7	1.354 (3)
O1—C2	1.373 (3)	C3′—O3′	1.358 (3)
C2—C3	1.361 (4)	C4′—O4′	1.364 (3)
C2—C1′	1.475 (4)	C5′—S1	1.764 (3)
C3—O3	1.352 (3)	S1—O1s	1.449 (2)
C3—C4	1.437 (4)	S1—O2s	1.460 (3)
C4—O4	1.260 (3)	S1—O3s	1.459 (3)
C5—O5	1.344 (3)		
C9—O1—C2	122.0 (2)	O1—C2—C1′	111.0 (2)
C3—C2—C1′	129.0 (3)	O3—C3—C4	116.6 (3)
C9—O1—C2—C3	2.0 (4)	O1—C2—C1′—C6′	2.4 (4)
O1—C2—C3—C4	1.2 (5)	O4′—C4′—C5′—S1	3.0 (4)
C2—O1—C9—C8	177.9 (3)	C4′—C5′—S1—O1s	−172.0 (3)
C7—C8—C9—O1	179.5 (3)		

Table 2
Hydrogen-bonding geometry (Å, °).

D—H···*A*	*D*—H	H···*A*	*D*···*A*	*D*—H···*A*
O5—H5···O4	0.93	1.78	2.623 (3)	149
O3—H3···O4	0.90	2.18	2.675 (3)	114
C2′—H2′···O3	0.93	2.24	2.886 (4)	126
C6′—H6′···O1	0.93	2.28	2.643 (3)	103
O7—H7···O3s^{i}	0.90	1.81	2.701 (3)	172
C8—H8···O1s^{i}	0.93	2.49	3.378 (4)	161
O4′—H4′···O7^{ii}	0.92	1.96	2.766 (3)	146
C6—H6···O3′^{iii}	0.93	2.48	3.350 (4)	157
O3—H3···O2s^{iv}	0.90	2.22	2.982 (3)	143
N1—H4n···O2s	0.92 (5)	1.94 (5)	2.845 (4)	168 (5)
N1—H2n···O3s^{v}	0.84 (5)	2.15 (5)	2.901 (4)	149 (5)
N1—H2n···O4′^{v}	0.84 (5)	2.58 (5)	3.155 (5)	127 (5)
N1—H3n···O4^{vi}	0.83 (5)	2.04 (5)	2.855 (5)	170 (5)
N1f—H2f···O1s	0.80 (5)	2.32 (5)	2.929 (4)	133 (5)
N1f—H3f···O1s^{i}	0.96 (5)	2.14 (5)	2.954 (5)	142 (5)
O3′—H3′···O1f^{vii}	0.89	1.79	2.668 (3)	170
C1f—H1f···O5^{viii}	0.96	2.34	3.303 (5)	179
N1—H1n···O1f^{ix}	0.91 (5)	2.06 (5)	2.808 (4)	138 (5)

Symmetry codes: (i) $1-x, 2-y, -z$; (ii) $x-1, y, 1+z$; (iii) $1+x, y, z-1$; (iv) $x, y-1, z$; (v) $-x, 2-y, 1-z$; (vi) $1-x, 1-y, 1-z$; (vii) $x, y-1, 1+z$; (viii) $x-1, 1+y, z$; (ix) $x, y, 1+z$.

All H atoms of the formamide and ammonium and of the hydroxyl groups of the quercetin-5′-sulfonate were located in a difference map [N—H = 0.80 (5)–0.96 (5) Å] and their positional parameters were refined. The remainder were positioned geometrically and allowed to ride on their parent atom, with U_{iso}(H) = 1.2 U_{eq}(C, N, O).

Data collection: *KM*-4 *Software* (Kuma Diffraction, 1991); cell refinement: *KM*-4 *Software*; data reduction: *KM*-4 *Software*; program(s) used to solve structure: *SHELXS*97 (Sheldrick, 1997); program(s) used to refine structure: *SHELXL*97 (Sheldrick, 1997); molecular graphics: *SHELXTL*/*PC* (Sheldrick, 1990); software used to prepare material for publication: *SHELXL*97 and *enCIFer* (Allen *et al.*, 2004).

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