Supplementary Information

Synthesis and structural characteristics of pyridine carboxylic acids adducts with squaric acid

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Table S1. The experimental and calculated, by the APF-D/6-311++G(d,p) approach, bond lengths (Å), bond angles (°) and selected torsion angles (°) for the complexes of squaric acid with picolinic acid (**1, 1a**), nicotinic acid (**2**, **2a**) and isonicotinic acid (**3**, **3a**).

	PICA-SQA		NICA-SQA			ISONICA-SQA		
	Exp	Calc	Exp		Calc	Exp		Calc
	1	**1a**	**2**	**2***	**2a**	**3**	**3***	**3a**
Bond lengths								
N(1)–C(2)	1.369(5)	1.340	1.339(2)	1.335(2)	1.344	1.344(2)	1.345(2)	1.350
C(2)–C(3)	1.368(5)	1.383	1.384(2)	1.383(2)	1.381	1.387(2)	1.388(2)	1.375
C(3)–C(4)	1.383(5)	1.390	1.390(2)	1.387(2)	1.392	1.392(2)	1.389(2)	1.396
C(4)–C(5)	1.384(5)	1.397	1.384(3)	1.380(3)	1.394	1.392(2)	1.395(2)	1.396
C(5)–C(6)	1.376(5)	1.380	1.379(2)	1.369(2)	1.377	1.380(2)	1.381(2)	1.375
C(6)–N(1)	1.344(4)	1.340	1.343(2)	1.347(2)	1.350	1.343(2)	1.340(2)	1.350
C(2)–C(7)	1.505(4)	1.525	–	–	–	–	–	–
C(3)–C(7)	–	–	1.495(2)	1.488(2)	1.526	–	–	–
C(4)–C(7)	–	–	–	–	–	1.510(2)	1.503(2)	1.529
C(7)–O(1)	1.253(3)	1.234	1.221(2)	1.235(2)	1.246	1.229(2)	1.227(2)	1.244
C(7)–O(2)	1.259(3)	1.251	1.311(2)	1.294(2)	1.241	1.292(2)	1.295(2)	1.244
C(11)–C(12)	1.397(4)	1.391	1.431(2)	1.425(2)	1.393	1.428(2)	1.429(2)	1.393
C(12)–C(13)	1.458(5)	1.483	1.436(2)	1.422(2)	1.482	1.432(2)	1.429(2)	1.482
C(13)–C(14)	1.525(5)	1.541	1.498(2)	1.497(2)	1.539	1.502(2)	1.505(2)	1.539
C(14)–C(11)	1.473(5)	1.482	1.498(2)	1.493(2)	1.482	1.500(2)	1.503(2)	1.482
C(11)–O(11)	1.289(4)	1.311	1.247(2)	1.258(2)	1.308	1.251(2)	1.252(2)	1.308
C(12)–O(12)	1.312(4)	1.309	1.321(2)	1.314(2)	1.308	1.312(2)	1.316(2)	1.308
C(13)–O(13)	1.228(4)	1.202	1.250(2)	1.253(2)	1.204	1.248(2)	1.244(2)	1.204
C(14)–O(14)	1.213(4)	1.203	1.221(2)	1.217(2)	1.204	1.215(2)	1.215(2)	1.204
*MAD	[a] 0.0139		[b] 0.0067		[c] 0.0239	[d] 0.0025		[e] 0.0022
Bond angles								
N(1)–C(2)–C(3)	119.2(4)	119.39	120.1(2)	119.7(2)	119.62	119.9(1)	119.8(1)	119.40
C(2)–C(3)–C(4)	119.7(4)	118.51	118.7(2)	118.5(2)	118.74	118.6(2)	118.5(1)	119.24
C(3)–C(4)–C(5)	120.2(5)	120.28	119.9(2)	120.4(2)	120.22	120.0(1)	120.4(1)	119.72
C(4)–C(5)–C(6)	119.0(4)	119.06	119.4(2)	119.0(2)	119.05	119.3(1)	118.7(1)	119.24
C(5)–C(6)–N(1)	120.1(3)	118.77	119.6(2)	119.9(2)	119.26	119.5(1)	119.9(1)	119.39
C(6)–N(1)–C(2)	121.9(3)	124.00	122.4(2)	122.5(2)	123.11	122.7(1)	122.8(1)	120.00
N(1)–C(2)–C(7)	115.8(3)	113.88	–	–	–	–	–	–
C(3)–C(2)–C(7)	125.0(4)	126.73	–	–	–	–	–	–
C(2)–C(3)–C(7)	–	–	120.4(2)	119.1(1)	119.11	–	–	–
C(4)–C(3)–C(7)	–	–	121.0(2)	122.4(2)	122.15	–	–	–
C(3)–C(4)–C(7)	–	–	–	–	–	122.6(1)	122.3(1)	120.14
C(5)–C(4)–C(7)	–	–	–	–	–	117.4(1)	117.3(1)	120.14
C(2)–C(7)–O(1)	117.1(3)	115.67	–	–	–	–	–	–
C(2)–C(7)–O(2)	115.0(3)	112.45	–	–	–	–	–	–
C(3)–C(7)–O(1)	–	–	122.1(2)	120.8(2)	114.28	–	–	–
C(3)–C(7)–O(2)	–	–	112.7(1)	113.7(2)	114.71	–	–	–
C(4)–C(7)–O(1)	–	–	–	–	–	118.2(1)	118.9(1)	114.50
C(4)–C(7)–O(2)	–	–	–	–	–	115.6(1)	115.1(1)	114.50
O(1)–C(7)–O(2)	127.8(3)	131.88	125.1(2)	125.5(2)	131.01	126.2(1)	126.1(1)	131.00
C(11)–C(12)–C(13)	93.0(3)	92.84	93.4(1)	93.4(1)	92.84	93.6(1)	93.9(1)	92.82
C(12)–C(13)–C(14)	87.6(3)	87.11	89.1(1)	89.4(1)	87.17	89.0(1)	89.1(1)	87.18
C(13)–C(14)–C(11)	87.4(3)	87.11	88.3(1)	87.8(1)	87.17	88.0(1)	87.9(1)	87.18
C(14)–C(11)–C(12)	92.0(3)	92.94	89.3(1)	89.4(1)	92.81	89.3(1)	89.2(1)	92.82
C(12)–C(11)–O(11)	137.8(4)	138.27	135.4(2)	136.4(2)	138.24	136.9(1)	136.7(1)	138.23
C14)–C(11)–O(11)	130.2(3)	128.79	135.3(2)	134.2(2)	128.95	133.8(1)	134.1(1)	128.94
C(11)–C(12)–O(12)	137.3(4)	132.38	135.7(1)	135.6(2)	138.22	135.4(1)	135.0(1)	133.23
C(13)–C(12)–O(12)	129.7(3)	128.79	130.9(2)	130.9(2)	128.96	131.0(1)	131.1(1)	128.94
C(12)–C(13)–O(13)	137.1(3)	135.46	135.7(2)	135.6(2)	135.47	136.4(1)	136.2(1)	135.47

C(14)–C(13)–O(13)	135.3(3)	137.42	135.2(2)	135.0(2)	137.36	136.2(1)	134.7(1)	137.35
C(11)–C(14)–O(14)	137.0(3)	135.45	135.8(2)	136.3(2)	135.48	136.8(1)	137.0(1)	135.47
C(13)–C(14)–O(14)	135.6(3)	137.45	135.9(2)	135.8(2)	137.35	135.2(1)	135.1(1)	135.35
MAD	[a)] 1.145		[b)] 0.491		[c)] 1.671	[d)] 0.304		[e)] 1.740
Torsion angles								
N(1)–C(2)–C(3)–C(4)	1.0(6)	0.02	−1.5(2)	1.6(2)	0.01	−0.1(2)	0.6(2)	–0.005
C(2)–C(3)–C(4)–C(5)	−1.1(8)	–0.02	0.6(2)	−1.1(3)	0.01	0.2(2)	−0.6(2)	0.002
C(3)–C(4)–C(5)–C(6)	0.5(9)	0.02	0.6(2)	−0.2(3)	–0.02	−0.6(2)	0.4(2)	0.003
C(4)–C(5)–C(6)–N(1)	0.3(7)	–0.001	−1.0(2)	1.0(3)	0.01	1.1(2)	−0.1(2)	–0.005
C(5)–C(6)–N(1)–C(2)	−0.4(6)	–0.005	0.2(2)	−0.5(3)	0.02	−1.1(2)	0.1(2)	0.002
C(6)–N(1)–C(2)–C(3)	−0.3(6)	–0.004	1.1(2)	−0.8(2)	–0.02	0.6(2)	−0.3(2)	0.003
C(6)–N(1)–C(2)–C(7)	−179.4(3)	–179.99	–	–	–	–	–	–
C(4)–C(3)–C(2)–C(7)	−179.9(4)	–179.99	–	–	–	–	–	–
N(1)–C(2)–C(3)–C(7)	–	–	177.7(1)	−178.2(2)	–179.99	–	–	–
C(5)–C(4)–C(3)–C(7)	–	–	−178.6(2)	178.7(2)	–179.99	–	–	–
C(2)–C(3)–C(4)–C(7)	–	–	–	–	–	−179.4(1)	179.1(1)	–180.00
C(6)–C(5)–C(4)–C(7)	–	–	–	–	–	179.0(1)	−179.4(1)	–180.00
N(1)–C(2)–C(7)–O(1)	−179.4(3)	179.59	–	–	–	–	–	–
N(1)–C(2)–C(7)–O(2)	0.6(5)	–0.36	–	–	–	–	–	–
C(3)–C(2)–C(7)–O(1)	1.5(6)	–0.40	–	–	–	–	–	–
C(3)–C(2)–C(7)–O(2)	−178.4(4)	179.65	–	–	–	–	–	–
C(2)–C(3)–C(7)–O(1)	–	–	−178.0(2)	6.4(2)	–0.45	–	–	–
C(2)–C(3)–C(7)–O(2)	–	–	1.4(2)	−173.9(2)	179.54	–	–	–
C(4)–C(3)–C(7)–O(1)	–	–	1.2(3)	−173.5(2)	179.55	–	–	–
C(4)–C(3)–C(7)–O(2)	–	–	−179.5(2)	6.3(2)	–0.46	–	–	–
C(3)–C(4)–C(7)–O(1)	–	–	–	–	–	−178.0(1)	−177.9(1)	179.87
C(3)–C(4)–C(7)–O(2)	–	–	–	–	–	2.5(2)	1.6(2)	–0.13
C(5)–C(4)–C(7)–O(1)	–	–	–	–	–	2.4(2)	1.8(2)	–0.13
C(5)–C(4)–C(7)–O(2)	–	–	–	–	–	−177.1(1)	−178.7(1)	179.87
C(11)–C(12)–C(13)–C(14)	−0.3(3)	0.28	−0.2(1)	0.4(1)	0.17	−1.1(1)	−0.7(1)	0.02
C(12)–C(13)–C(14)–C(11)	0.2(3)	–0.26	0.2(1)	−0.4(1)	–0.16	1.1(1)	0.7(1)	–0.02
C(13)–C(14)–C(11)–C(12)	−0.3(3)	0.28	−0.2(1)	0.4(1)	0.17	−1.1(1)	−0.7(1)	0.02
C(14)–C(11)–C(12)–C(13)	0.3(3)	–0.29	0.2(1)	−0.4(1)	–0.18	1.1(1)	0.7(1)	–0.02
C(13)–C(12)–C(11)–O(11)	−179.1(5)	179.75	−179.0(2)	179.5(2)	179.86	−177.6(2)	−178.2(2)	179.93
C(13)–C(14)–C(11)–O(11)	179.2(5)	–179.75	179.0(2)	−179.6(2)	–179.86	177.7(2)	178.3(2)	–179.98
O(11)–C(11)–C(12)–O(12)	1.2(8)	–0.20	0.0(4)	0.1(4)	–0.12	2.3(3)	0.2(3)	–0.03
O(11)–C(11)–C(14)–O(14)	−0.8(8)	0.33	−0.1(4)	2.1(4)	0.18	−1.6(3)	−1.8(3)	0.03
C(14)–C(11)–C(12)–O(12)	−179.5(5)	179.76	179.2(2)	−179.8(2)	179.85	179.0(2)	179.1(2)	179.98
C(14)–C(13)–C(12)–O(12)	179.5(5)	-179.76	−179.2(2)	179.8(2)	–179.85	−179.0(2)	−179.2(2)	–179.98
O(12)–C(12)–C(13)–O(13)	−0.8(8)	0.32	−0.5(3)	−0.9(3)	0.20	−2.0(3)	0.3(3)	0.03
C(11)–C(12)–C(13)–O(13)	179.4(5)	–179.63	178.5(2)	179.7(2)	–179.78	177.9(2)	178.8(2)	–179.98
C(11)–C(14)–C(13)–O(13)	−179.5(5)	179.65	−178.5(2)	−179.7(2)	179.79	−178.0(2)	−178.9(2)	179.98
O(13)–C(13)–C(14)–O(14)	0.5(8)	–0.44	0.6(4)	−1.3(4)	–0.25	1.4(3)	1.2(3)	–0.03
C(12)–C(11)–C(14)–O(14)	179.8(5)	–179.64	−179.3(2)	−178.0(2)	–179.79	179.6(2)	179.2(2)	–179.98
C(12)–C(13)–C(14)–O(14)	−179.8(5)	179.65	179.3(2)	178.0(2)	179.80	−179.6(2)	−179.2(2)	179.98

Mean absolute difference, MAD = $1/n \sum|d_{exp} - d_{calc}|$; d – geometrical parameter; n – number of data; MAD between bond lengths or bond angles, respectively of [a)] **1** and **1a**, [b)] **2*** and **2**, [c)] **2*** and **2a**, [d)] **3*** and **3**, [e)] **3*** and **3a**

* The atoms of one from two independent hydrogen squarate monoanions and pyridinium-carboxylic acid cations in the asymmetric unit of **2** and **3** crystal structures are described by the capital letter A.

Table S2. Determined ΔpK_a parameters for described pyridine carboxylic acid – squaric acid systems.

Pyridine carboxylic acid	pK_aH^+ [a)]	ΔpK_a [b)]
PICA (picolinic acid)	1.03	0.31
NICA (nicotinic acid)	1.96	1.37
ISONICA (isonicotinic acid)	1.57	0.98

a) pK_a(protonated base) values calculated by potentiometric measurements by B. García et al. (pK_1 parameter in this work)[1]; b) ΔpK_a = pK_a(protonated base) – pK_a(acid)[2]. The squaric acid pK_{a1} value of 0.59 was taken into account for the calculation of ΔpK_a parameter[3].

References

1 B. García, S. Ibeas and J. M. Leal, *J. Phys. Org. Chem.*, 1996, **9**, 593–597.
2 A. J. Cruz-Cabeza, *CrystEngComm*, 2012, **14**, 6362–6365.
3 R. I. Gelb, *Anal. Chem.*, 1971, **43**, 1110–1113.

Table S3. Summary of the contact contributions in the Hirshfeld surface area of the asymmetric units in crystals of 1, 2, and 3. The two dominant interactions are marked in bold.

	O···H / %	C···H / %	N···H / %	others / %	Sum of top two interactions / %
1	**48**	**16.6**	0.3	35.1	64.6
2	**48**	**17.4**	0.9	33.7	65.4
3	**41.5**	**19.3**	1.1	38.1	60.8

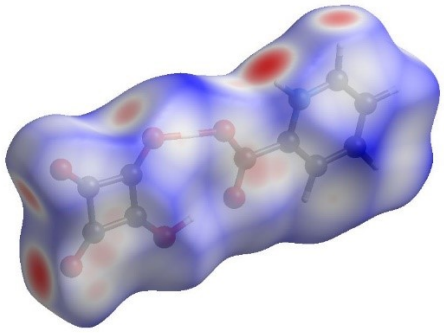

Fig. S1 The Hirshfeld surface of asymmetric unit of **1** generated using d_{norm} parameters in the range -0.5914 – 1.1053.

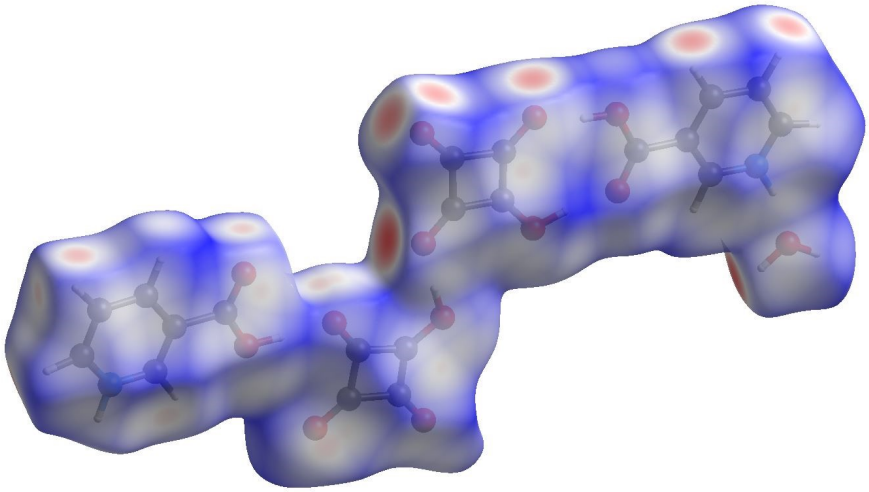

Fig. S2 The Hirshfeld surface of asymmetric unit of **2** generated using d_{norm} parameters in the range -0.7245 – 0.9707.

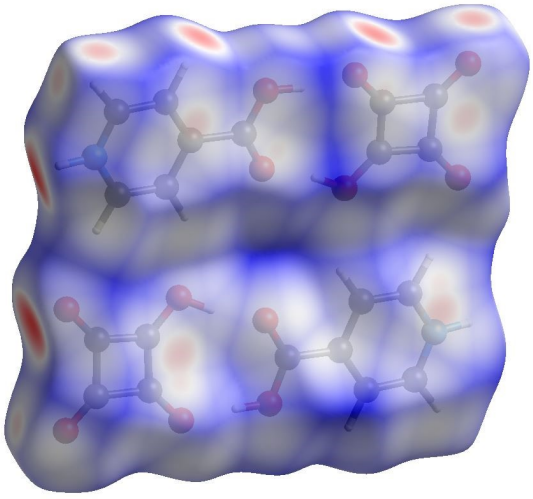

Fig. S3 The Hirshfeld surface of asymmetric unit of **3** generated using d_{norm} parameters in the range -0.7530 – 0.9507.

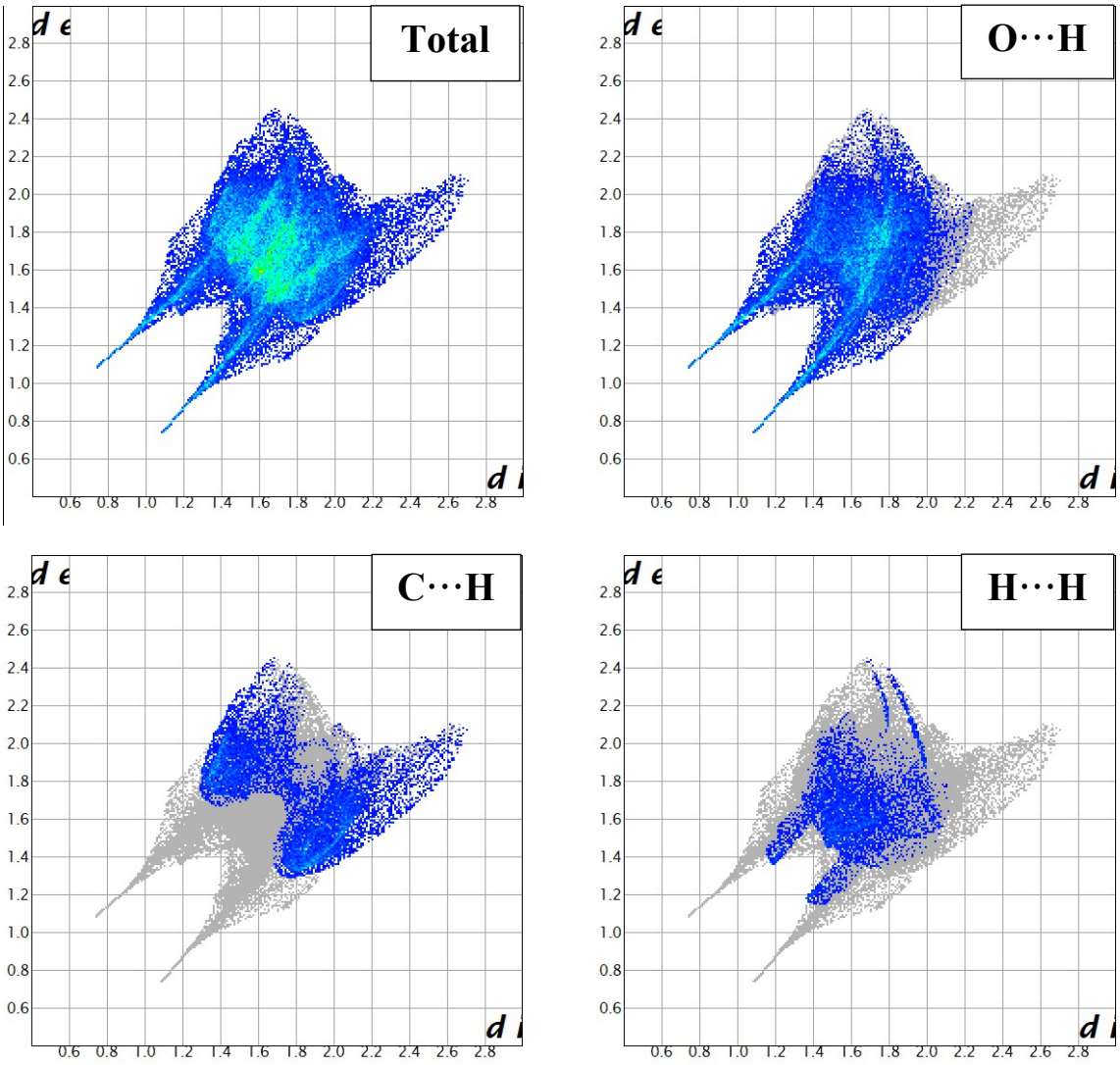

Fig. S4 2D fingerprint plots of asymmetric unit in crystal of pyridinium-2-carboxylate squaric acid (**1**).

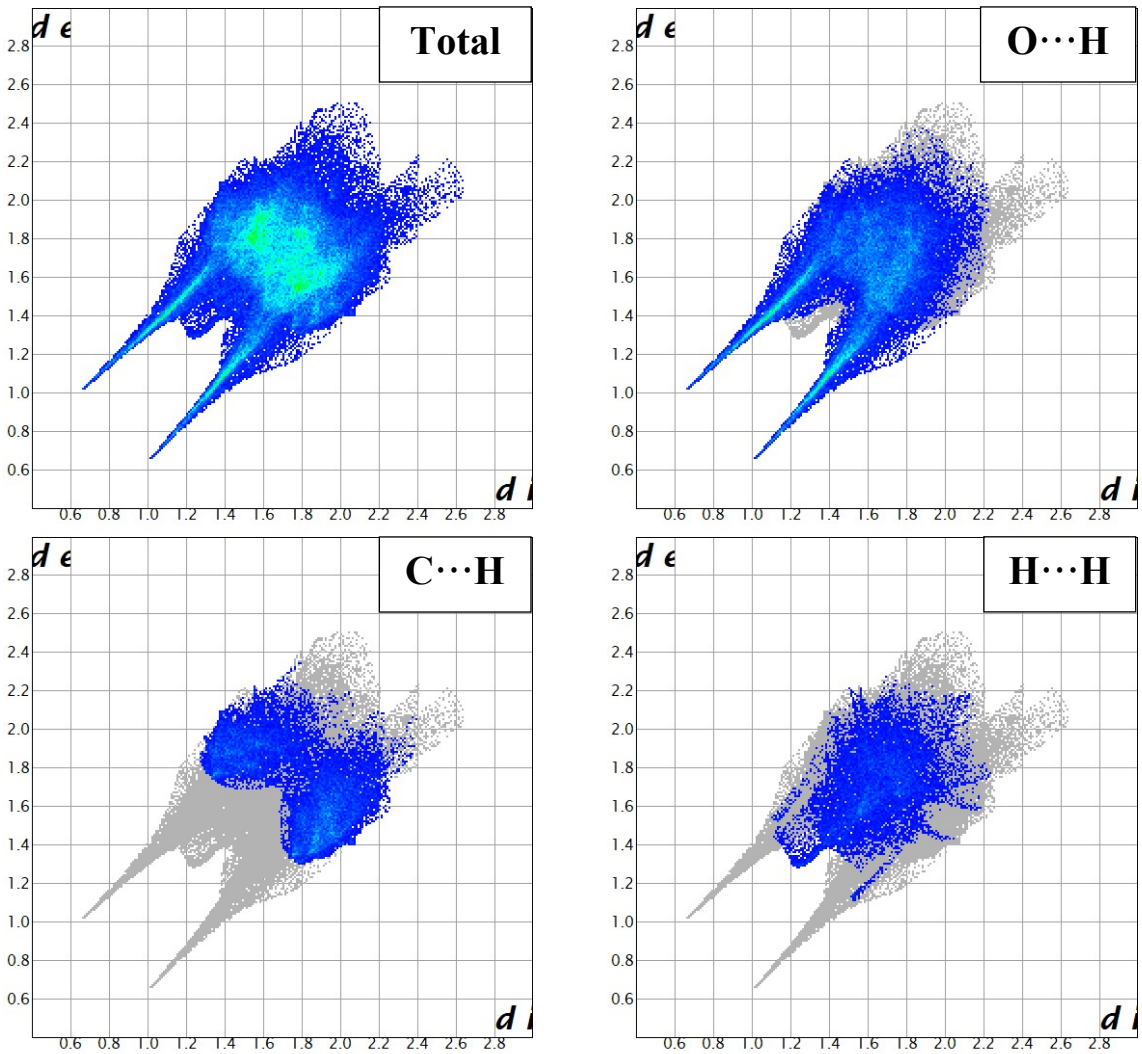

Fig. S5 2D fingerprint plots of asymmetric unit in crystal of pyridinium-3-carboxylic acid squaric acid hemihydrate (**2**).

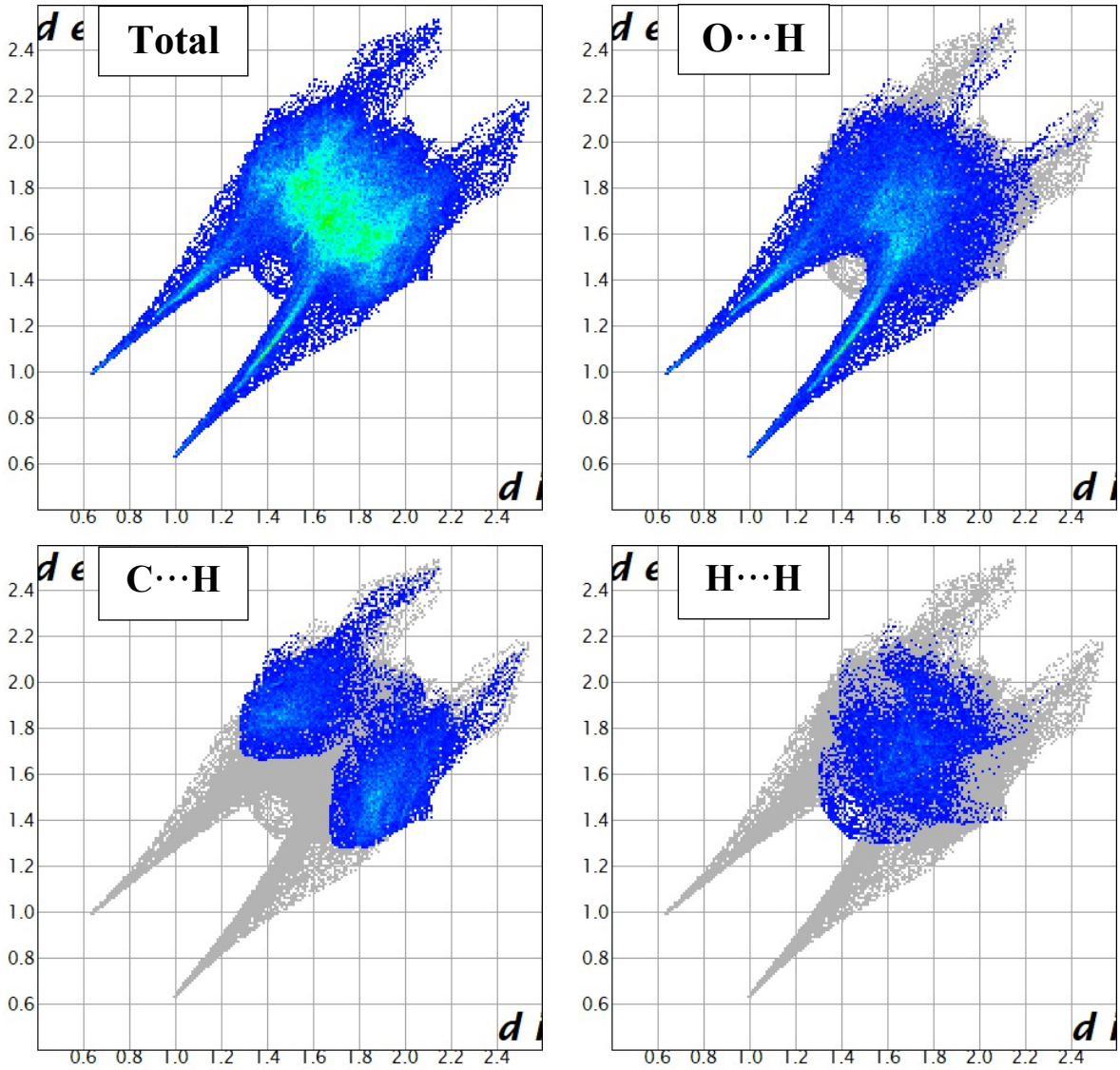

Fig. S6 2D fingerprint plots of asymmetric unit in crystal of pyridinium-4-carboxylic acid squaric acid (**3**).

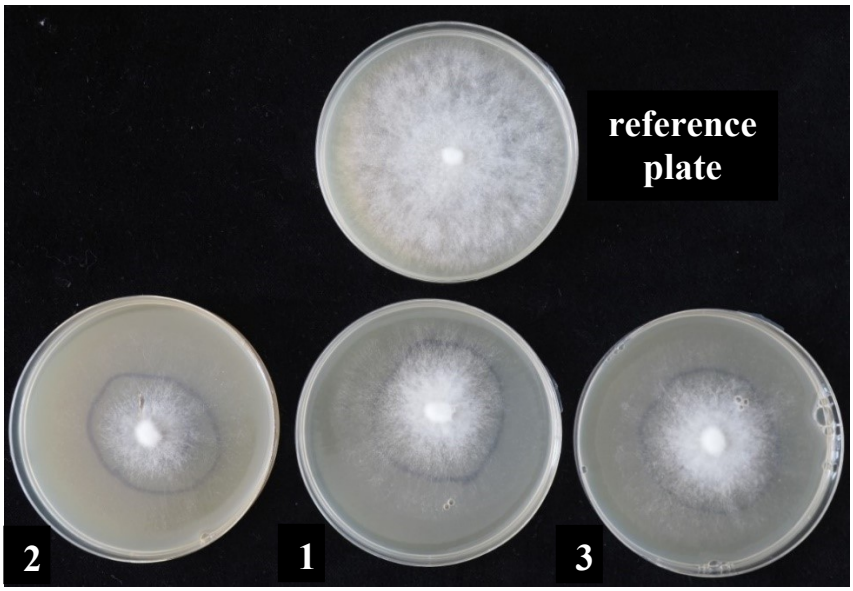

Fig. S7 The experimental determination of ED_{50} of the fungistatic properties with *Poria placenta* fungus for pyridinium-2-carboxylate squaric acid (**1**), pyridinium-3-carboxylic acid hydrogen squarate hemihydrate (**2**), pyridinium-4-carboxylic acid hydrogen squarate (**3**).