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Graphical abstract

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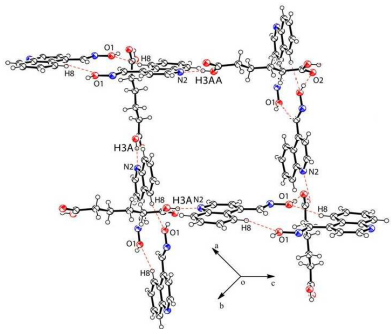

Synthons in the cocrystals and salts of quinoline-4-carbaldoxime with acids are discussed

A. Tarai, J. B. Baruah

Oxime synthons in the salts and cocrystals of quinoline-4-carbaldoxime for non-covalent synthesis

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Abstract:

The oxime-quinoline $R^2_2(8)$ type heterosynthons in self-assemblies of quinoline-4-carbaldoxime changes to form $R^2_2(14)$ type oxime-oxime homosynthons and quinoline-carboxylic acid heterosynthons in cocrystals on interactions with dicarboxylic acids such as adipic, succinic and fumaric acid. General trend in the formation of similar oxime-oxime homosynthons of these cocrystals is useful to demarcate as predesigned non-covalent synthesis. On the other hand, the maleate salt of quinoline-4-carbaldoxime has two self-interacting maleate anions flanked by two quinolinium-4-carbaldoxime cations whereas in the oxalate salt has the dianions flanked by two cations. Among the salts of acids like nitric acid and hydrochloric acid, the nitrate salt has nitrate

ions bridging two quinolinium-4-carbaldoxime cations to form cyclic motifs whereas, the self-assembly of the chloride salt has chloride water chains through hydrogen bonds. The self-assembly of the chloride salt has conventional $R^2_2(8)$ type oxime-oxime homosynthons.

Introduction:

Oximes are used in detection of nerve gas[1a-b] and in detection of explosives[1c-f]. Wide ranges of self-assemblies can be constructed from oxime derivatives[2] which is attractive to supramolecular chemists. In view of rapid emergence on utilities of synthons[3] in predesigned non covalent synthesis assemblies of oximes have high potential. Oximes interact with biomolecules[4] and amine-oxime interactions have helped in delivery of oxime based drug by nanoscale polymer carrier.[5] Substrate dependent biological activities shown by oxime derivative such as piperidin-4-one oxime ethers[6] provide impetus to explore the supramolecular chemistry of various oxime derivatives. Quinoline aldoximes interacts with DNA and some of them show antibacterial activities.[7] Despite of extensive study on the oximes to form different assemblies, due to lesser affinity for interaction between an oxime and carboxylic acids the assemblies with carboxylic acids are less studied.[8]

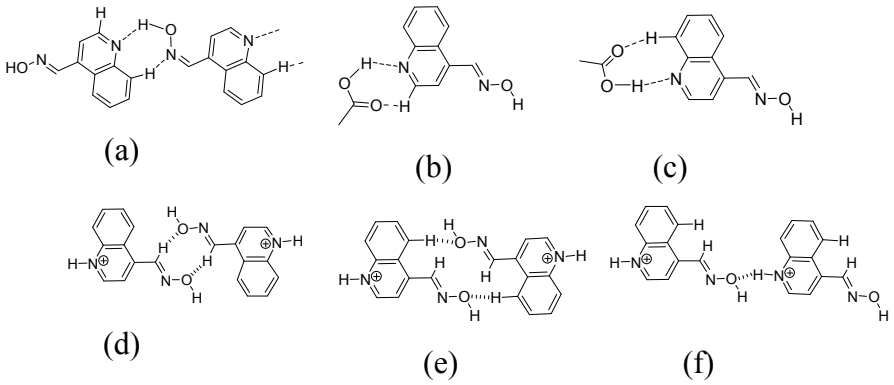


Figure 1: (a) The self-assembly of quinoline-4-carbaldoxime. (b-c) Some probable hydrogen bonded motifs in cocrystals of quinoline-4-carbaldoxime with carboxylic acids and in (d-f) salts of quinoline-4-carbaldoxime.

The structure of quinoline-4-carbaldoxime was reported in literature[9a] and it possesses hydrogen bonded heterosynthons (a of Fig. 1) having the N...H-O as the principal interaction. Upon interactions of this oxime with a carboxylic acid such heterosynthons may transform to other synthons such as b-e of Fig. 1. Formation of such heterosynthons would depend on the extent of proton transfer with the partner carboxylic acid. The homosynthon d (Fig. 1) is conventional and is observed in self-assemblies of aldoximes[2] whereas the $R^2_2(14)$ type synthon (e of Fig. 1) is the replica synthon of 1-(hydroxyiminomethyl)-2-naphthol.[9b] Both these synthons are guided by weak C-H...O interactions and the latter compound has a nitrogen atom which can be protonated or should be able to exchange proton with an acidic hydrogen of a partner molecules while forming a salt or a corystal. Such process would guide the self assembly process by changing the hydrogen bond partners of oxime group in the cocrystals or salts of quinoline-4-carbaldoxime which has not been explored and is a important fact to understand too develop new structures. On the other hand, the structural frame of the 1-(hydroxyiminomethyl)-2-naphthol is closely related to the structural frame of the quinoline-4-carbaldoxime. Former molecule has naphthalene carbocycle attached to an aldoxime, whereas latter has aldoxime attached to a quinoline heterocycle. Hence, a proton transfer or a proton sharing with a foreign molecule at the nitrogen site of quinoline-4-carbaldoxime should change heterosynthons of quinoline-4-carbaldoxime to the homosynthons similar to that of the one present in self assemblies of the 1-(hydroxyiminomethyl)-2-naphthol. Beside this, quinoline-4-carbaldoxime is chosen as it is an amphoteric compound, which is a prospective candidate to form self-assemblies with acidic and basic compounds and identification of the self assemblies formed would provide a guideline for understanding of different self-assemblies. With such objectives we studied self-assemblies of various cocrystals and salts of quinoline 4-carbaldoxime.

Results and discussion:

Due to two functional units present in the quinoline-4-carbaldoxime to form hydrogen bonds, it can choose a partner molecule to hold by one functional unit or both these sites by forming hydrogen bonds. Thus, there is possibility for quinoline moiety to interact with an acid or a base partner. Such interactions can be through proton-transfer to have electrostatic interactions or by forming hydrogen bonds with a partner molecule. It is observed that quinoline-4-carbaldoxime easily forms cocrystals or crystalline salts with acids such as adipic, succinic, maleic, fumaric,

oxalic, hydrochloric and nitric acid. But crystals either in the form of cocrystals or salts of quinoline-4-carbaldoxime with nitrogen containing compounds such as imidazole, pyrazole, picoline and pyridine could not be prepared from solution of these compounds with quinoline-4-carbaldoxime in different solvents (methanol, DMF, THF, acetone etc). In these cases starting oxime crystallised out from these solutions which were confirmed by recording ^{1}HNMR spectra of the crystals formed in each case. This is attributed to the stability of the heterosynthon (a of Fig. 1) which is primarily guided by O-H...N interactions of the parent compound and these weakly basic compounds likely not to disrupt such synthons. Accordingly, a series of cocrystals and salts of quinoline-4-carbaldoxime dicarboxylic acids and mineral acids listed in Fig. 2 were prepared and structurally characterised.

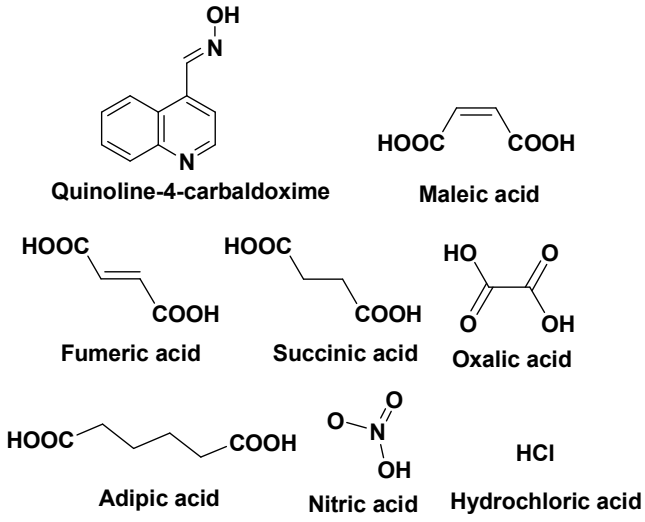
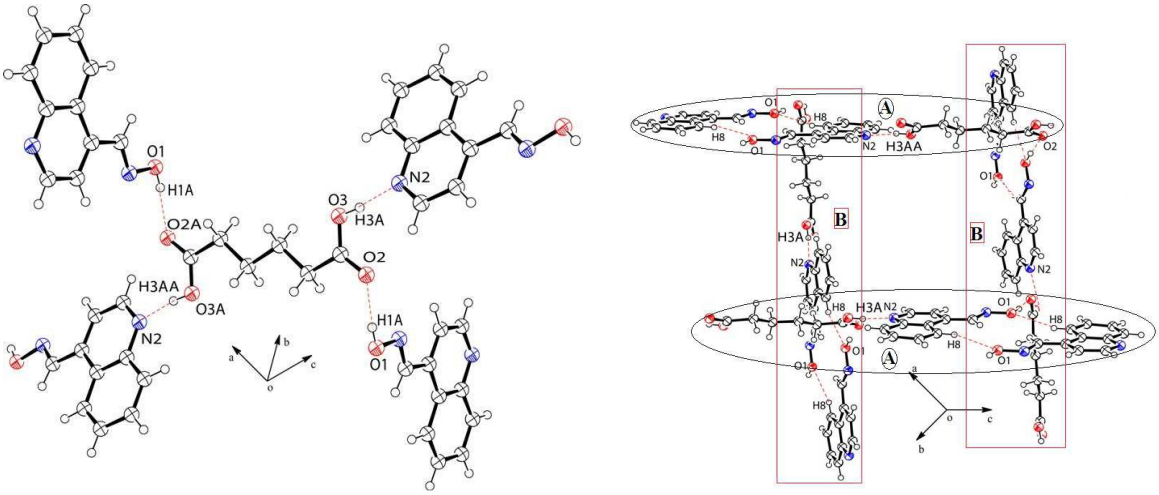


Figure 2: Quinoline-4-carbaldoxime and acid partners.

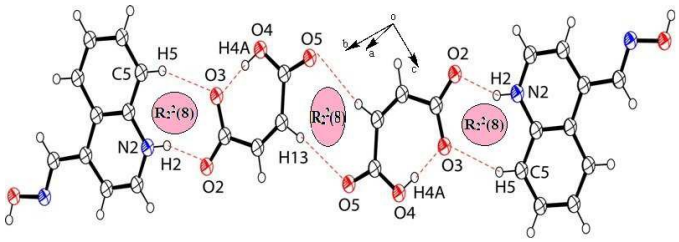
From structural investigation we found that quinoline-4-carbaldoxime forms cocrystal with adipic acid, succinic acid or fumaric acid whereas it formed salts with maleic, oxalic, nitric or hydrochloric acid. All the cocrystals have 2:1 molar ratio. Among the salts of carboxylic acids maleate salt had 1:1 molar ratio between oxime and maleate, whereas in the case of oxalate salt the ratio of oxime to oxalate was 2:1.The extent of deprotonation of maleic acid and oxalic acid are different, which decided the composition of these two salts.



(a) (b)

Figure 3: (a) Hydrogen bonded assemblies of adipic acid cocrystal (b) Self-assemblies of adipic acid cocrystal with quinoline-4-carbaldoxime.

The structures of the cocrystals of quinoline-4-carbaldoxime and adipic acid, succinic acid, and fumaric acid have close resemblances. Due to such similarity only the structure of cocrystal with adipic acid is discussed. The hydrogen bonded assembly of the cocrystal is shown in Fig. 3a. Self-assembly of the cocrystal has O-H…N hydrogen bonds in which the quinoline nitrogen atom forms hydrogen bonds with the O-H of the succinic acid. The other prominent O-H...O hydrogen bonds in the lattice of the cocrystal which is formed between the carbonyl of the carboxylic acids with the OH of neighboring oxime molecules. These two interactions helped these molecules to self assemble and generated cyclic assemblies. The self-assemblies are constituted by the combination assemblies of a pair of two oxime molecules with a dicarboxylic acid molecule designated as A in Fig. 3b held by another two pairs of two oxime molecules and a dicarboxylic acid designated as B in Fig. 3b. Beside these cocrystals have $R_2^2(7)$ cyclic hydrogen bond motifs in their lattice involving C-H...O interactions. The $R_2^2(7)$ motif is guided by C4-H4...O2 interactions (Fig. S1-S2). The H...O bonds of the C-H...O interactions are in the range of 2.62 to 2.78Å with ∠D-H...A angles 120.9°, 124.4°, 123.7°, respectively for the cocrystal with adipic acid, succinic and fumaric acid cocrystal respectively. From geometrical consideration these interactions are very weak,[10] but the ∠D-H...A angle has an ascending trend



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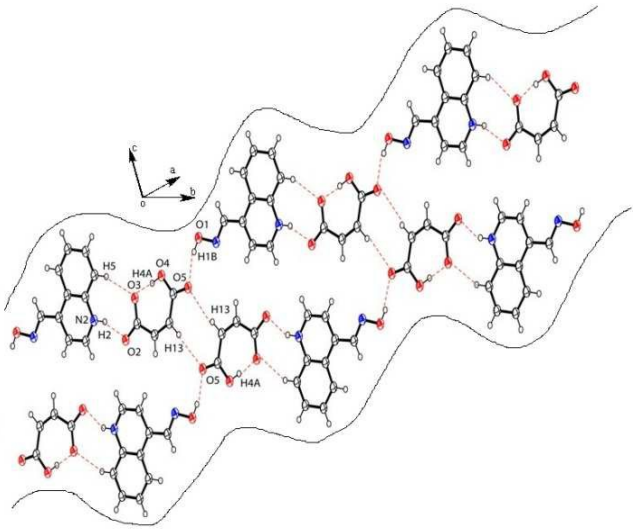


(b)

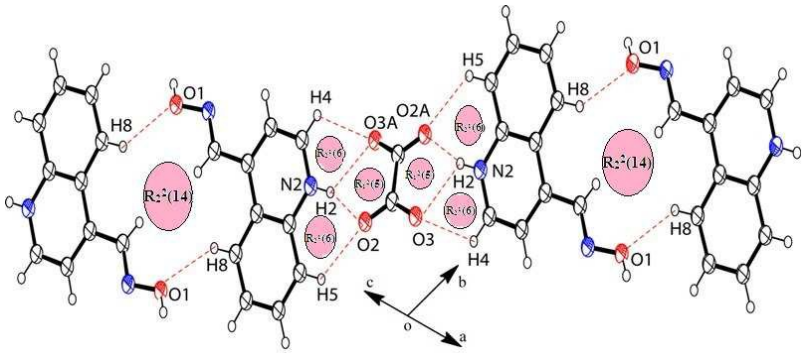
Figure 4: The self-assembly of (a) Maleate salt and (b) Packing pattern of maleate salt with quinoline-4-carbaldoxime (ORTEPs are with 30% thermal ellipsoids)

with the intervening methylene groups increasing between the carboxylic acids. As the flexibility of the dicarboxylic acid molecule of the cocrystals increases the relevance of such C-H...O bond decreases. Generally aldoximes form homosynthons of $R^2_2(8)$ type as illustrated Fig. 1d, but such synthons[2] are not observed in these cocrystals as the carboxylic acid disrupts the C-H...O bonded homosynthons due to hierarchy of O-H...N and O-H...O interactions incorporated by carboxylic acid groups. The cocrystals of quinoline-4-carbaldoxime with aliphatic dicarboxylic acids are comprised of uniformly distributed one type of assembly as confirmed by comparison of the powder XRD patterns of the bulk samples with the powder XRD pattern generated from the CIF file of the single crystal data.

The quinoline-4-carbaldoxime reacted with maleic acid to form a salt having 1:1 molar ratio of cation and anion. The salt has a mono anion of maleic acid with a prtonated quinoline-4-carbaldoxime molecule. Mono anion formation is attributed to high pKa_1 value of maleic acid which arises due to stabilisation of mono anion through intramolecular hydrogen bonds. Two maleate anions self assemble to form $R^2_2(8)$ type of homosynthons by C-H...O and O-H…O interactions (Fig. 4a). These dimeric sub-assemblies are embedded by two quinolinium-4-carbaloxime cations through formation of $R^2_2(8)$ motifs involving N-H...O and C-H...O interactions. Such sub-assemblies form the basis of the repeated units, they are placed face-to-face in one direction to form chain-like structures. The C-H...O interactions between the C5-H5 bond of quinoline with carbonyl of the maleate and the O-H groups of oxime interacting with carbonyl of the dicarboxylic acid at the other end are responsible to build chain-like architecture. The packing pattern of maleate salt is shown in Fig. 4b. Maleic acid and fumaric acids are two geometrical isomers and they form cocrystals in different proportions with partner molecules[11] and they also adopt different hydrogen bonding patterns and packing patterns. In our present case we also observe cocrystal formation by quinoline-4-carbaldoxime with fumaric acid whereas salt formation with maleic acid. The result on maleic acid salt can be summarised by Etter's rule[12] which says that the six member intramolecular hydrogen bonded motif is formed and the proton donors and acceptors remaining after this participate in intramolecular hydrogen bonds. Accordingly in the case of a cyclic intramolecular hydrogen bonded six member meleate anion is formed which further forms the hydrogen bonded homo and heterosynthons. However, there is also a point to be noted in all the cocrystals and salts all the good donors and acceptors for hydrogen bonds are utilised in self assembly formation.

An oxalate salt having cation and anion ratio in 1 : 2 ratio was obtained from the reaction of quinoline-4-carbaldoxime with oxalic acid. In the crystal packing of this salt the oxalate ions are held between two quinoline-4-carbaldoxime cations (Fig. 5a). The packing is guided by bifurcated hydrogen bonds having C-H…O and N-H…O interactions. The later interaction is ionic nature, hence contributes strongly to such an assembly. Presence of oxalate dianions makes the assembly of the salt to differ from the assemblies of the maleate salt which is a mono anionic salt. Hydrogen bonding between oxime OH and oxalate anion is shown in Fig. 5b. For the

comparison hydrogen bond parameters in the assemblies of the cocrystals and salts are given in table 1.



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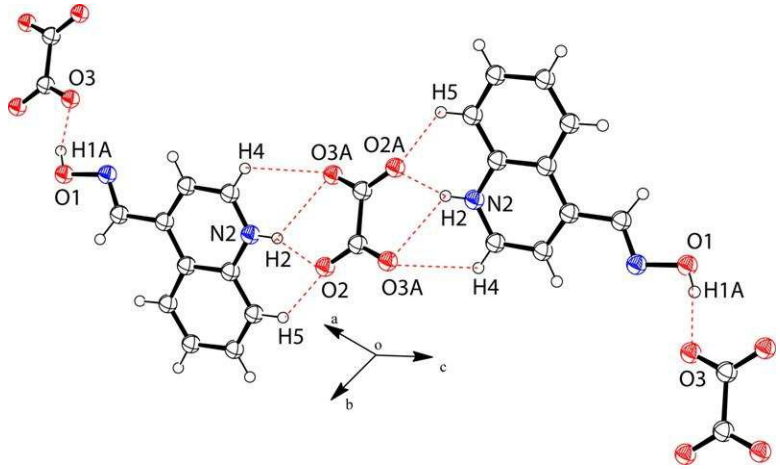


(b)

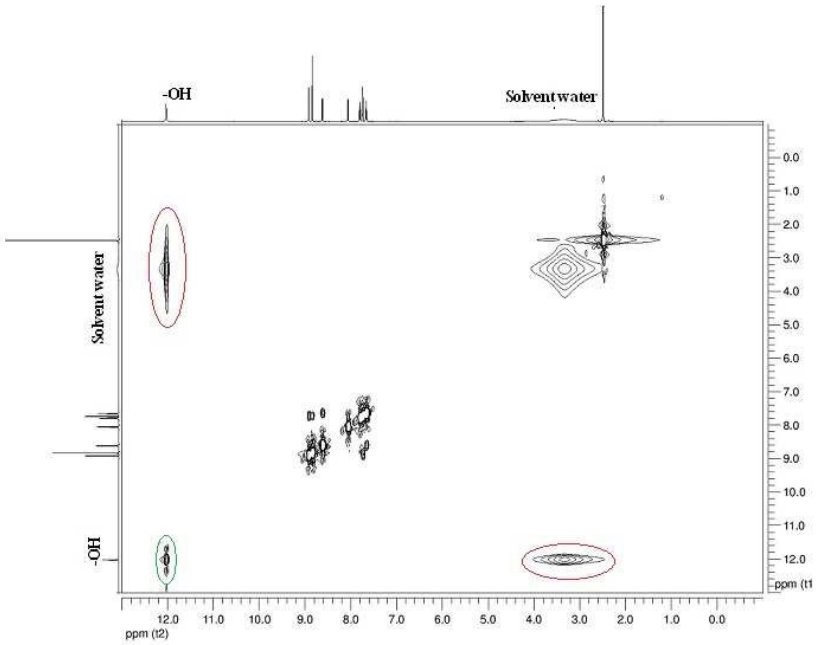
Figure 5: Cyclic hydrogen motif in (a) Oxalate salt and (b) Hydrogen bonding between oxime OH and acidic partner in oxalate salt.

Table 1: Hydrogen bond parameters of the cocrystals and salts of quinoline-4-carbaldoxime

Cocrystal/Salt	D-H…A	d_{D-H} (Å)	$d_{H...A}$ (Å)	$d_{D...A}$ (Å)	∠D-H…A (°)
Cocrystal with adipic acid	O(1)-H(1A)…O(3) [-1+x, -1+y, z]	0.82	1.89	2.702(19)	169
	O(2)-H(2)…N(2) [1/2-x, -1/2+y, 1/2-z]	0.82	1.74	2.559(2)	171
	C(8)-H(8)…O(1) [-x, -y, 1-z]	0.93	2.52	3.426(3)	163
Cocrystal with succinic acid	O(1)-H(1A)…O(2) [-1+x, 1+y, z]	0.82	1.84	2.655(19)	172
	O(3)-H(3A)…N(2) [1/2-x, 1/2+y, 1/2-z]	0.82	1.77	2.586(2)	173
	C(8)-H(8)…O(1) [-x, 2-y, 1-z]	0.93	2.44	3.284(2)	151
Cocrystal with fumaric acid	O(1)-H(1A)…O(3) [-1+x, -1+y, z]	0.82	1.84	2.655(2)	173
	O(2)-H(2)…N(2) [1/2-x, -1/2+y, 1/2-z]	0.82	1.76	2.578(2)	176
	C(8)-H(8)…O(1) [-x, -y, -z]	0.93	2.44	3.273(2)	149
Oxalate salt	O(1)-H(1A)…O(3) [1-x, 1-y, -z]	0.82	1.79	2.586(15)	163
	N(2)-H(2)…O(3) [1-x, 1-y, -z]	0.86	2.43	2.994(18)	124
	N(2)-H(2)…O(2) [-x, 1-y, 1-z]	0.86	1.85	2.665(18)	159

Maleate salt	O(1)-H(1B)…O(5) [2-x, 1-y, 1-z]	0.82	1.85	2.651(2)	166
	N(2)-H(2)…O(2) [-x, -y, 1-z]	0.86	1.87	2.681(2)	156
	C(5)-H(5)…O(3) [-x, -y, 1-z]	0.93	2.44	3.302(3)	154
	C(7)-H(7)…O(4) [x, y, -1+z]	0.93	2.41	3.263(3)	152
	C(13)-H(13)…O(5) [1-x, 1-y, 1-z]	0.93	2.51	3.437(3)	175
Chloride salt	O(1)-H(1)…O(2) [1/2-x, 1/2+y, 1/2-z]	0.82	1.82	2.600(8)	158
	O(2)-H(2A)…Cl(1)	1.05(6)	2.20(6)	3.117(8)	144(6)
	N(2)-H(2A)…Cl(1) [x, -1+y, z]	0.86	2.19	3.030(7)	166
	O(2)-H(3A)…Cl (1) [3/2-x, -1/2+y, 1/2-z]	0.97(10)	2.19(10)	3.094(10)	156(6)
	C(1)-H(1A)…O(1) [-x, 1-y, -z]	0.93	2.59	3.436(9)	152
Nitrate salt	O(1)-H(1)…O(4) [-1+x, y, z]	0.82	1.92	2.717(19)	164
	N(2)-H(2)…O(2) [x, -1+y, 1+z]	0.86	2.50	3.091(18)	127
	N(2)-H(2)…O(4) [x, -1+y, 1+z]	0.86	1.92	2.778(17)	173

Since the self-assemblies of the salts and cocrystals are guided by proton transfer or exchange from the carboxylic acids ^{1}H-NOESY spectra of two representative salt (Fig. 6a) and cocrystal (Fig. 6b) one each were recorded. The oxime hydroxy group interacts with the residual water molecules in DMSO-d^{6} solvent. This is reflected in the correlation peak appearing at 12 ppm and peak appearing at 3.35 ppm. The ^{1}H-NOESY experiments are based on double quantum coherence and relates directly to the spin-lattice relaxation. The correlation peak obtained from the salt is broader than the cocrystal, which is suggestive of the fact that in salt the proton transfer is slower. The relative slow exchange of the proton in the case of the salt is attributed to the stronger interactions of the hydrogen atom by nitrogen atom in the salt reduced the exchange of oxime OH with the (+)N-H group. This is also revealed in the ordinary proton NMR where the salt with oxalic acid showed a broad peak in the OH region. In both these cases the carboxylic acid OH or (+)N-H signals of quinoline merges with the water signal from residual water present in the solvent.



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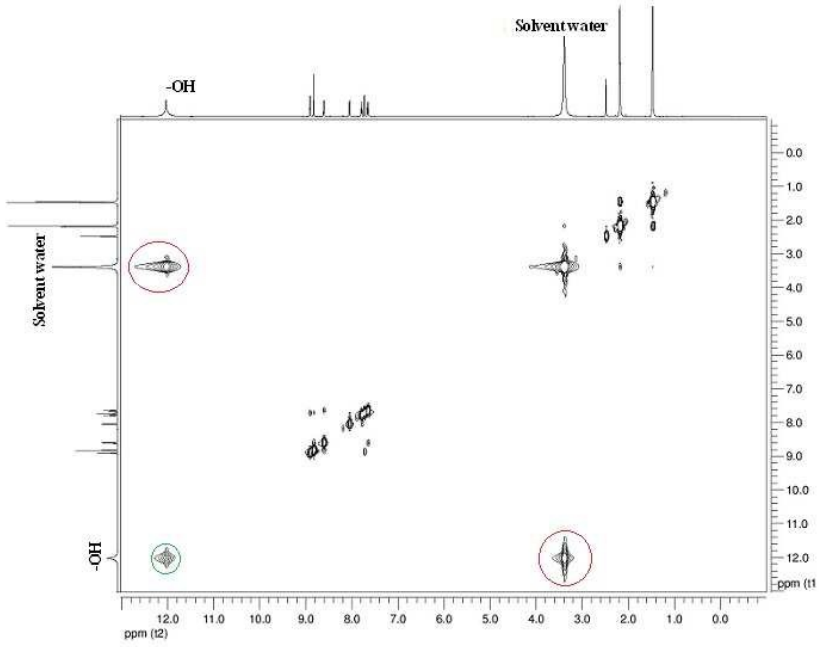


(a)

Figure 6: ^{1}H-NOESY spectra (600MHz, DMSO-d^{6}) of (a) Cocrystals of quinoline-4-carbaldoxime and adipic acid and (b) Oxalate salt of quinoline-4-carbaldoxime (encircled ones are the cross peaks showing NOE effect).

Both the salts are anhydrous and no hydrated crystals were revealed in the powder XRD patterns of the salts. In an earlier example we have shown that the maleic acid salt of quinoline derivative was colored, whereas the cocrystals with fumaric acid was colourless.[13] In the present case also the salts are yellowish whereas the cocrystals are colourless.

To compare the self-assemblies of salts of inorganic acids with the carboxylate salts, the structures of the chloride and the nitrate salt were studied. The self-assembly of the chloride salt is guided by three strong hydrogen bonds to maintain a T-shape environment (Fig. 7a). The chloride salt was exclusively formed as mono hydrate which was confirmed by powder XRD pattern of the bulk sample of the salt (Fig. 7c).

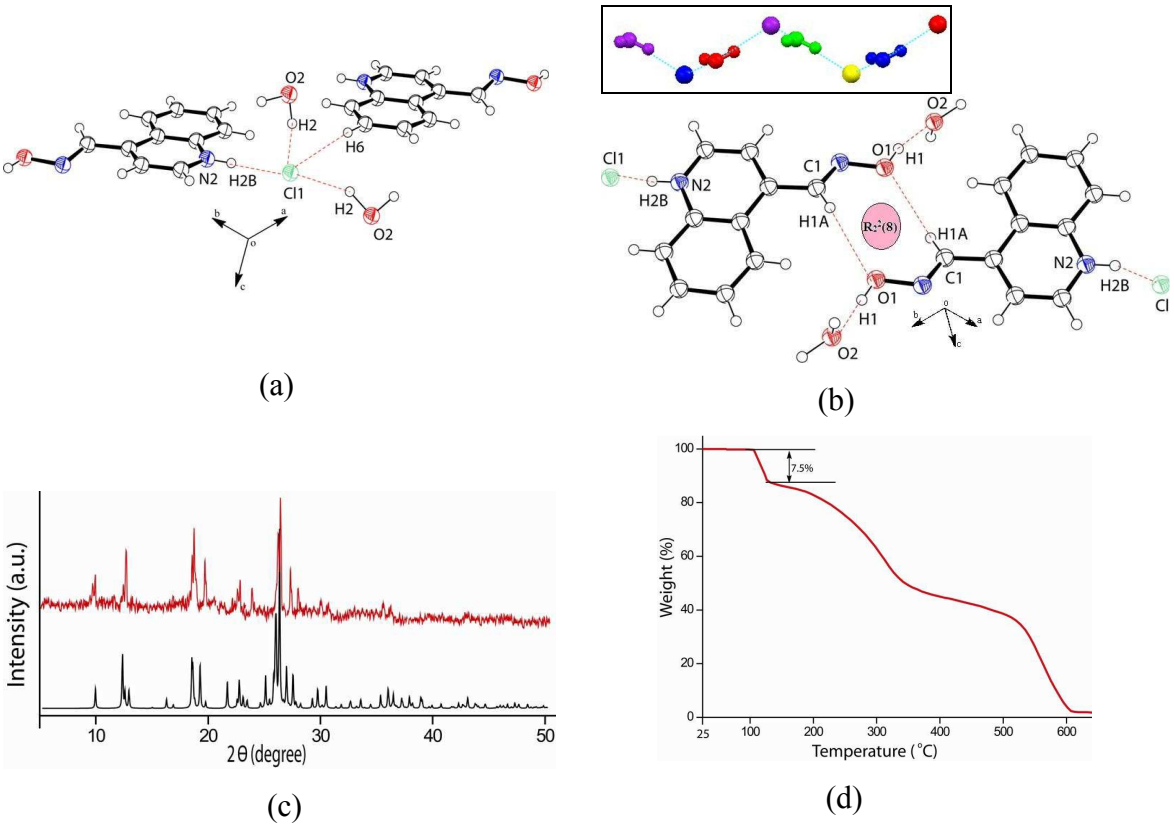


Figure 7: (a) The hydrogen bonds of chloride ions in lattice of the chloride salt. (b) Two interacting units of oximes in the self-assembly of the chloride salt. In the inset is the chloride water chain in chloride salt. (c) Powder XRD pattern of the chloride salt. (d) TGA of the salt (heating rate 10°C/min).

Such geometry are observed in self-assemblies of molecules in which chloride ions were in hydrogen bond environments.[14] To adopt such a geometry in the present example chloride ion utilises two water molecules and results in the formation of chloride water chains (Fig. 7b). The structure of the chloride salt can be imagined as arrangements of protonated quinoline oxime molecules held on the channel by strong (+)N-H...Cl interactions. Due to such arrangements the quinoline rings are not available to form the $R^2_2(14)$ type homosynthons observed in the salts and cocrystals; but it forms $R^2_2(8)$ type homosynthons (Fig. 1d) involving the aldehydic C-H interacting with the oxygen atom of the oxime. This is a regular synthon observed in assemblies of aldoximes.[2] To reduce repulsions between similar ions in the lattice and to involve the donor O-H unit of oxime in hydrogen bond scheme, the OH of the oxime group hydrogen bonds to water molecules. Thus, the water molecules act also as the bridging molecules to anchor the chloride ions together with another oxime molecule of the assembly forming a spiral chain-like structure along the b-crystallographic axis. Hence, it may be suggested that due to formation of chain-like structures having (+)N-H...Cl interactions and to adopt T-shape hydrogen bond environment around chloride ion, the water molecules interacting with chloride are embedded in the lattice as filler molecules. Aquated chloride[15] ions have relevance in natural environments as chloride is abundant in sea water or as sea-salt aerosols. The trapping of different forms of water-chloride associates in various crystal have revealed them to exist in different forms such as clusters, one- or two-dimensional hydrogen-bonded networks.[14] Hexameric hybrid water–chloride–ethanol octamers are stabilized by quinoline containing cobalt complexes, the present water cluster comprise of one-dimensional chain-like structure with alternating water molecules and chloride ions. Thermogravimetric analysis (TGA) of the mono hydrate is shown in Fig. 7d have shown weight loss in the region of 100-110ºC due to evaporation of water molecules. The weight loss corresponded to loss of one water molecule per salt molecule; which left no ambiguity that only the mono hydrate was formed. The bulk sample also showed identical TGA leaving no doubt about mono hydrate being the sole product.

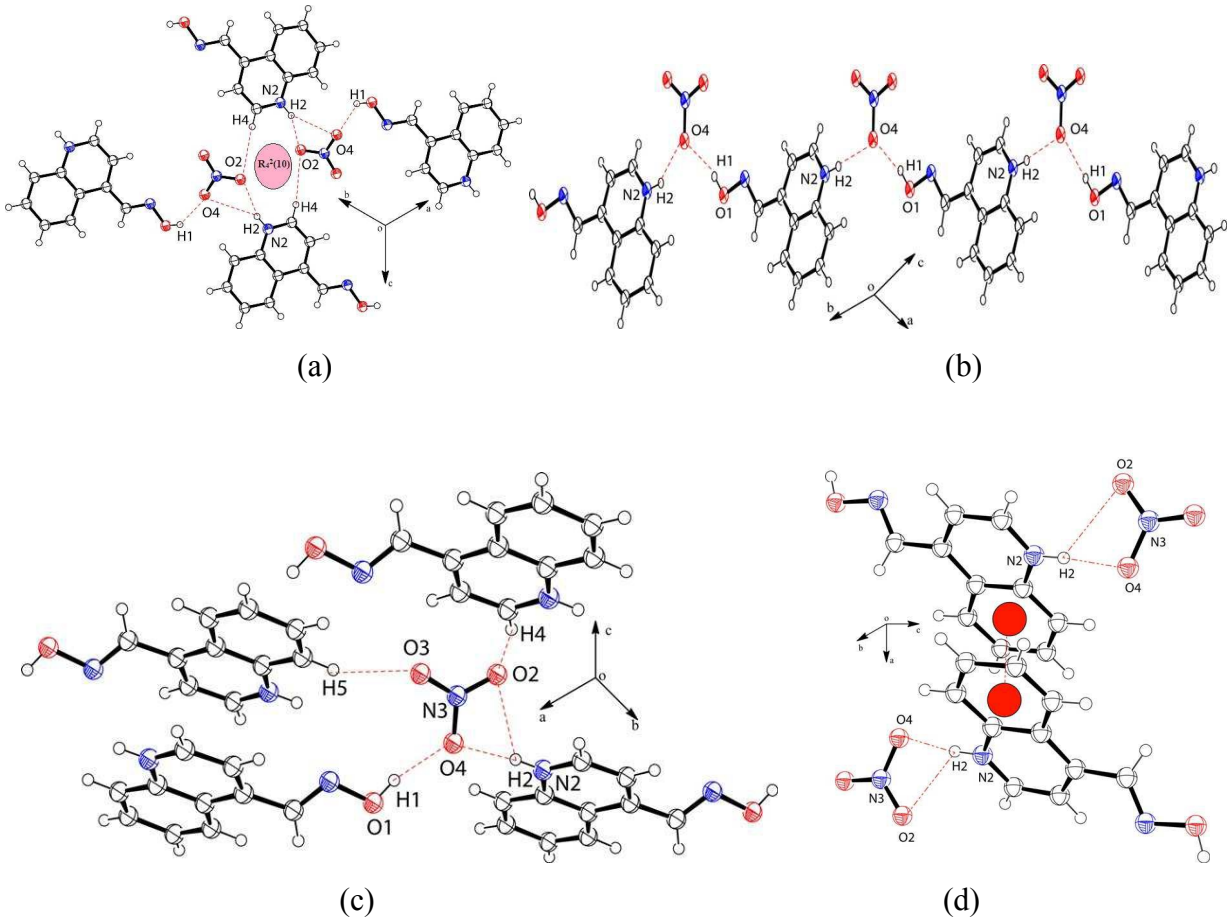
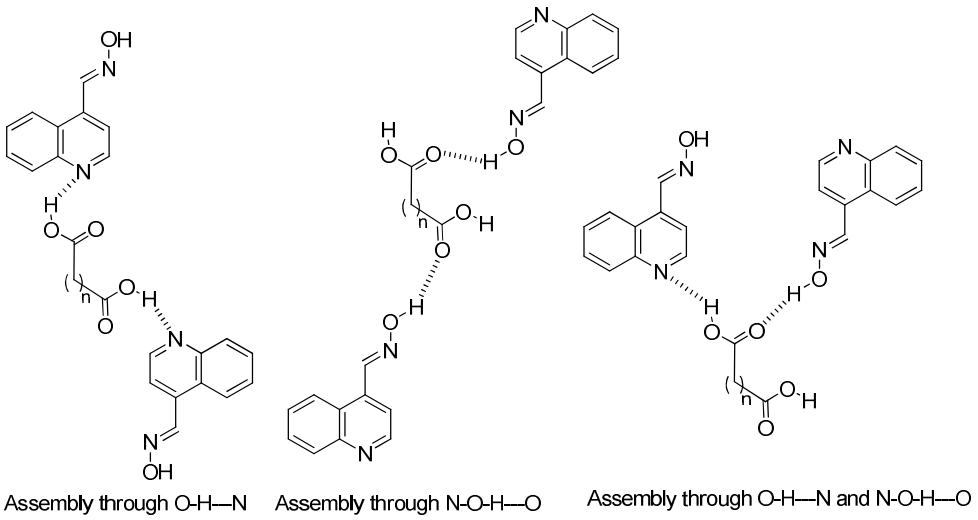


Figure 8: (a) Cyclic type hydrogen bond motifs of nitrate ions in lattice of the nitrate salt. (b) Bifurcated hydrogen bonds in nitrate salt. (c) One nitrate ion interacts with four protonated quinoline-4-carbaldoxime molecules. (d) π-π interaction between two quinoline-4-carbaldoxime molecules in nitrate salt.

Nitrate salt of quinoline 4-carbaldoxime has an interesting structure and it has the nitrate ions assisting in formation of cyclic sub-assemblies. The nitrate ions occurs as pairs and such arrangements are formed by bifurcated hydrogen bond between the (+)N-H with two oxygen atom of nitrate and sub-assemblies are held together by C4-H...O4 interaction as shown in Fig. 8a. These dimeric motifs are held by two O-H...O interactions between oxime O-H bond and oxygen (O4) atoms of the nitrate. In general nitrate ions can form planar structures through complementary hydrogen bonds with host molecules or get encapsulated in host molecules.[16] In the present case the nitrate ions form two dimensional non planar sheet in which the nitrate ions

are slightly oblique from orientation with respect to the plane of quinoline oxime molecules. There is also $R^2_2(14)$ type homosynthons similar to the one observed in the self-assembly of salts exception being the chloride salt. The difference in the chloride salt could be due to the participation of aquated anions in the self assembly, in all other cases the salts are anhydrous. Different types of hydrogen bonds between nitrate anion and cationic host molecules that are observed in the nitrate salt are shown in Fig. 8b-d.



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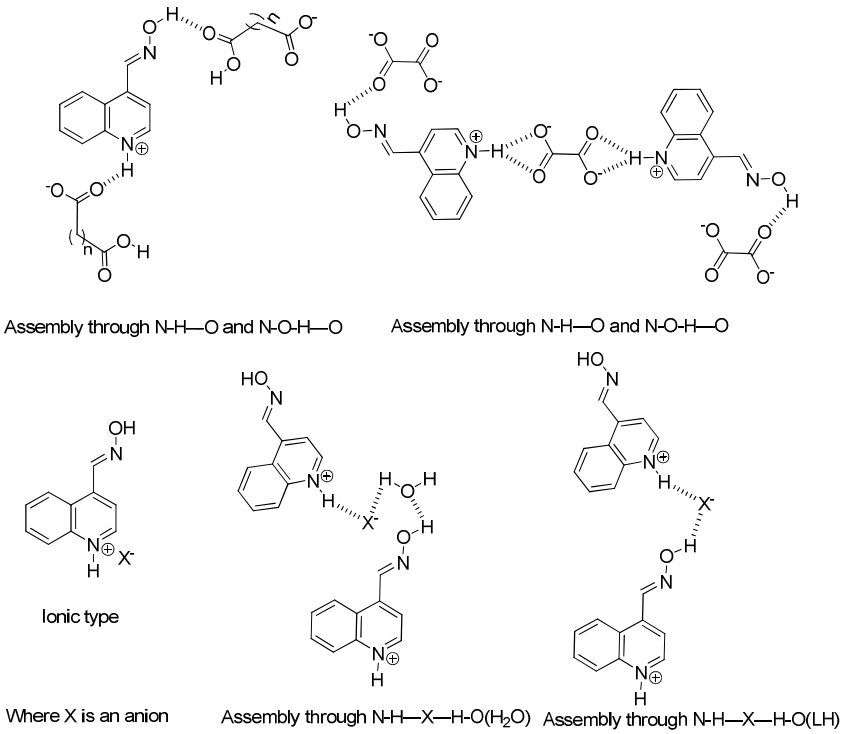

(b)

Figure 9: Observed hydrogen bonded motifs contributing to the assemblies of quinoline-4-carbaldoxime with acid partners in the (a) Cocrystals and (b) Salts.

To summarise this structural study, several types of hydrogen bonds in the self assemblies are observed, among them the prominent hydrogen bonds are shown in Fig. 9. In the present study, we have observed that oxime O-H forms strong hydrogen bond with corresponding acid partner. From earlier studies it is clear that oxime prefers to form cocrystals with basic compounds.[2] Quinoline moiety of quinoline 4-carbaldoxime forms O-H...N hydrogen bond with oxime to form its self-assembly.[9a] While acid is added to quinoline 4-carbaldoxime, N atom of quinoline part of the molecule prefers to bind with carboxylic acid OH. These types of interactions are routinely come across as a part of synthons of pyridine-carboxylic acid or quinoline-carboxylic acid systems.[11] This facilitates the other site (the carbonyl oxygen) of the carboxylic acid to bind to OH of the oxime group as shown in Fig. 9a. The (carboxyl)O-H…N(pyridine) and (pyridine)C-H….O(carbonyl) hydrogen bonds which have similarity to the quinoline-carboxylic acid interactions were shown to control self-assembly of pyridine-carboxylic acid assemblies,[17] in our case there is synergic contributions from the (carboxyl)O-H…N(quinoline) and (oxime)O-

H…O(carbonyl) of oxime-carboxylic acid interactions guiding the self-assembling of the cocrystals.

Thus such self assemblies are guided by O-H...O and N-H...O synthons. This may be also one of the reasons that the unconventional carboxylic acid oxime interactions are observed in the present systems under discussion. In the self-assemblies of the cocrystals, carboxylic acids contribute in a dual manner; they form the cocrystal by interacting with the oxime and they also anchor such cocrystals by providing extension to hydrogen bonded assembly by acting as bridges between the cocrystal units. On the other hand the inherent directional properties associated with anions plays a major role to guide the packing pattern of the respective salt.

Conclusions:

It has been shown that the cocrystals of quinoline-4-carbaldoxime with dicarboxylic acids can be self-assembled to form cyclic sub-assemblies as the basis of robust self-assemblies. The systematic observation to obtain similar sub-assemblies from cocrystals of three closely related dicarboxylic acids has made it possible to use the synthons for non-covalent synthesis in predictive manner from understanding of one analogue. The packing patters of the salts of dicarboxylic acids are guided by extent of deprotonation to form anion. In the case of mono maleate anion a cyclic motif is formed through intramolecular hydrogen bond, which is the characteristic signature of a mono maleate anion and found in the salt. The hydrated chloride salt has oxime-oxime interactions through $R^2_2(8)$ type homosynthons. Homosynthons formed between protonated oxime molecules in the respective self-assemblies of the salts are influenced by anions. From this analysis it may be suggested that the extent of deprotonation of a dicarboxylic acid and proton sharing play important roles which are to be considered for a predesigned building of such soft materials.

Experimental Section:

Infrared spectra of the solid samples were recorded on a Perkin-Elmer Spectrum-One FT-IR spectrophotometer in the region 4000-400 cm^{-1} by making KBr pellets. Powder X-ray diffraction patterns were recorded using Bruker powder X-ray diffractometer D2 phaser. The 1H-NMR spectra were recorded on a Varian 400 MHz NMR spectrometer using TMS as internal standard.

Synthesis of quinoline-4-carbaldoxime was carried out by reported procedure.[9] Cocrystals and salts were obtained by slow evaporation of a solution of the quinoline-4-carbaldehyde oxime and respective guest in methanol-DMF mixture in appropriate molar ratio.

Cocrystal of quinoline-4-carbaldoxime with adipic acid: Isolated yield: 74%. ^{1}H-NMR (400 MHz, DMSO-d^{6}): 12.03 (s, 1H), 8.93 (d, J = 4.4 Hz, 1H), 8.85 (s, 1H), 8.64 (d, J = 8.4 Hz, 1H), 8.06 (d, J = 8.4 Hz, 1H), 7.82 (t, J = 6.8 Hz, 1H), 7.75 (d, J = 4.4 Hz, 1H), 7.68 (t, J = 8.4, 1H), 2.20 (m, 4H), 1.49 (m, 4H). IR (KBr, cm^{-1}): 3045 (br, m), 2962 (w), 1695 (s), 1583 (s), 1517 (m), 1488 (m), 1462 (s), 1428 (m), 1408 (m), 1358 (m), 1328 (w), 1279 (s), 1247 (w), 1193 (s), 1142 (w), 1042 (s), 927 (s), 856 (m), 818 (m), 756 (s), 735 (s), 688 (m), 612 (w), 512 (s).

Cocrystal of quinoline-4-carbaldoxime with succinic acid: Isolated yield: 71%. ^{1}H-NMR (400 MHz, DMSO-d^{6}): 12.03 (s, 1H), 8.93 (d, J = 4.4 Hz, 1H), 8.85 (s, 1H), 8.64 (d, J = 8.4 Hz, 1H), 8.08 (d, J = 8.4 Hz, 1H), 7.80 (m, 1H), 7.75 (d, J = 4.4 Hz, 1H), 7.67 (m, 1H), 2.41 (m, 2H), 2.08 (m, 2H). IR (KBr, cm^{-1}): 3050 (br, m), 2989 (w), 1680 (m), 1583 (s), 1517 (s), 1486 (s), 1458 (m), 1421 (w), 1372 (w), 1330 (s), 1295 (m), 1243 (s), 1178 (s), 1143 (m), 1047 (s), 1022 (w), 993 (m), 923 (s), 857 (s), 817 (s), 802 (m), 786 (m), 765 (s), 661 (s), 603 (m), 554 (s), 537 (m), 516 (s).

Cocrystal of quinoline-4-carbaldoxime with fumaric acid: Isolated yield: 75%. ^{1}H-NMR (400 MHz, DMSO-d^{6}): 12.03 (s, 1H), 8.93 (d, J = 4.4 Hz, 1H), 8.85 (s, 1H), 8.64 (d, J = 8.4 Hz, 1H), 8.08 (d, J = 8.4 Hz, 1H), 7.80 (t, J = 6.8, 1H), 7.75 (d, J = 4 Hz, 1H), 7.67 (t, J = 8, 1H), 2.41 (s, 1H), 2.08 (s, 1H). IR (KBr, cm^{-1}): 3137 (br, m), 2989 (w), 1679 (m), 1585 (s), 1517 (s), 1486 (s), 1459 (m), 1373 (w), 1331 (s), 1296 (m), 1244 (s), 1208 (m), 1181 (s), 1145 (m), 1048 (s), 1023 (w), 987 (m), 970 (m), 924 (s), 857 (s), 818 (s), 792 (s), 765 (s), 668 (s), 602 (m), 559 (s), 536 (m), 516 (s).

Oxalate salt of quinoline-4-carbaldoxime**:** Isolated yield: 78%. ^{1}H-NMR (400 MHz, DMSO-d^{6}): 12.07 (s, 1H), 8.94 (d, J = 4.4 Hz, 1H), 8.85 (s, 1H), 8.64 (d, J = 8.8 Hz, 1H), 8.08 (d, J = 8 Hz, 1H), 7.83 (t, J = 6.8 Hz, 1H), 7.76 (d, J = 4.8 Hz, 1H), 7.69 (t, J = 8, 1H). IR (KBr, cm^{-1}): 3329 (br, m), 3048 (w), 2946 (w), 1634 (s), 1578 (s), 1498 (m), 1460 (m), 1409 (w), 1375 (m), 1325 (w), 1306 (m), 1281 (w), 1238 (w), 1127 (m), 1056 (s), 1025 (s), 997 (s), 919 (s), 846 (s), 808 (m), 760 (s), 658 (m) 648 (s), 528 (s).

Maleate salt of quinoline-4-carbaldoxime**:** Isolated yield: 81%. ^{1}H-NMR (400 MHz, DMSO-d^{6}): 12.08 (s, 1H), 8.95 (d, J = 4.4 Hz, 1H), 8.86 (s, 1H), 8.65 (d, J = 8.8 Hz, 1H), 8.09 (d, J = 8.4 Hz, 1H), 7.83 (t, J = 6.8 Hz, 1H), 7.78 (d, J = 4 Hz, 1H), 7.69 (t, J = 8, 1H), 6.25 (s, 1H), 2.03 (s, 2H). IR (KBr, cm^{-1}): 3066 (br, m), 2923 (w), 1693 (w), 1633 (m), 1592 (m), 1490 (w), 1448 (s), 1349 (s), 1271 (m), 1235 (w), 1216 (m), 1055 (m), 994 (s), 865 (s), 784 (m), 766 (m), 737 (m), 658 (s), 573 (s), 527 (s).

Chloride salt of quinoline-4-carbaldoxime: Isolated yield: 73%. ^{1}H-NMR (400 MHz, DMSO-d^{6}): 12.89 (s, 1H), 9.17 (d, J = 5.5 Hz, 1H), 9.07 (s, 1H), 8.82 (d, J = 8.8 Hz, 1H), 8.34 (d, J = 8.4 Hz, 1H), 8.15 (d, J = 5.6 Hz, 1H), 8.08 (t, J = 6.8 Hz, 1H), 7.91 (t, J = 7.2, 1H). IR (KBr, cm^{-1}): 3229 (br, m), 3058 (w), 2956 (w), 1627 (s), 1558 (s), 1530 (m), 1448 (m), 1381 (m), 1362 (m), 1323 (m), 1274 (s), 1237 (s), 1143 (s), 1043 (s), 991 (s), 888 (m), 840 (s), 759 (s), 534 (s).

Nitrate salt of quinoline-4-carbaldoxime: Isolated yield: 75%. ^{1}H-NMR (400 MHz, DMSO-d^{6}): 12.88 (s, 1H), 9.21 (d, J = 5.2 Hz, 1H), 9.09 (s, 1H), 8.84 (d, J = 8 Hz, 1H), 8.23 (d, J = 8.8 Hz, 1H), 8.19 (d, J = 5.6 Hz, 1H), 8.10 (t, J = 6.8 Hz, 1H), 7.93 (t, J = 7.2, 1H). IR (KBr, cm^{-1}): 3223 (br, m), 3096 (w), 2956 (w), 1637 (s), 1594 (s), 1540 (m), 1460 (s), 1383 (s), 1321 (s), 1292 (m), 1274 (m), 1221 (s), 1152 (w), 1104 (s), 1049 (s), 1029 (s), 989 (s), 927 (s), 885 (s), 854 (s), 817 (w), 770 (s), 720 (s), 655 (s), 630 (w), 533 (s).

Crystallographic Study: X-ray single crystal diffraction data for the cocrystals and salts were collected at 298 K with Mo Kα radiation (λ = 0.71073 Å) with the use of a Bruker Nonius SMART APEX CCD diffractometer equipped with a graphite monochromator and an Apex CCD camera. SMART software was used for data collection and also for indexing the reflections and determining the unit cell parameters. Data reduction and cell refinement were performed using SAINT and XPREP software. Multiscan empirical absorption corrections were carried out with the help of face-indexing. Structures were solved by direct methods using SHELXS-97 and were refined by full-matrix least-squares on F^2 using SHELXL-97. All non-H atoms were refined in anisotropic approximation against F^2 of all reflections. H atoms were placed at their calculated positions and refined in the isotropic approximation; some of the hydrogen atoms of water molecules of crystallization and coordinated water molecules could not be located and left as

such. Crystallographic data collection was done at room temperature, and data are tabulated in Table 2**.**

Table 2: Crystallographic parameters of the cocrystals and salts of quinoline-4-carbaldoxime

Compounds	Adipic acid cocrystal	Succinic acid cocrystal	Fumaric acid cocrystal	Maleate salt	Oxalate salt	Nitrate salt	Chloride salt
Formula	$C_{13}H_{13}N_2O_3$	$C_{12}H_{11}N_2O_3$	$C_{12}H_{10}N_2O_3$	$C_{14}H_{12}N_2O_5$	$C_{11}H_9N_2O_3$	$C_{10}H_9N_3O_4$	$C_{10}H_{11}N_2O_2Cl$
CCDC no.	1417579	1417580	1417581	1417578	1417577	1417576	1417575
Mol.wt.	245.25	231.31	230.20	288.26	217.20	235.20	226.66
Space group	P 2_1/n	P 2_1/n	P2_1/n	P-1	P -1	P -1	P 21/n
a/Å	12.7021(5)	12.7915(5)	12.6838(12)	5.3961(7)	4.9838(2)	7.9402(7)	7.650(9)
b/Å	5.0401(2)	5.0009(2)	5.0451(5)	9.4163(13)	9.8417(4)	8.1717(8)	7.943(8)
c/Å	19.1216(8)	16.4829(7)	16.3375(16)	13.6395(17)	10.3031(5)	8.8975(8)	18.15(2)
α/°	90.00	90.00	90.00	75.670(9)	100.059(3)	70.343(6)	90.00
β/°	98.951(3)	90.926(3)	90.201(7)	89.392(9)	100.517(3)	89.333(6)	92.26(2)
γ/°	90.00	90.00	90.00	80.448(8)	91.372(3)	72.343(6)	90.00
V/Å3	1209.25(9)	1054.26(7)	1045.45(18)	661.83(15)	488.42(4)	515.42(8)	1102(2)
Density/g cm^{-3}	1.347	1.457	1.463	1.446	1.477	1.515	1.366
Abs. coeff./mm^{-1}	0.097	0.107	0.107	0.112	0.110	0.120	0.328
F(000)	516	484	480	300	226	244	472
Total no. of reflections	2151	1843	1892	2322	1706	1864	1975
Reflections, I > 2σ(I)	1488	1341	1402	1591	1441	1097	1250
Max. θ/°	25.24	25.24	25.24	25.25	25.25	25.24	25.24
Ranges (h, k, l)	$-15 \le h \le 15$ $-5 \le k \le 5$ $-22 \le l \le 22$	$-15 \le h \le 15$ $-6 \le k \le 5$ $-19 \le l \le 19$	$-15 \le h \le 15$ $-5 \le k \le 6$ $-19 \le l \le 19$	$-6 \le h \le 6$ $-10 \le k \le 11$ $-15 \le l \le 16$	$-5 \le h \le 5$ $-11 \le k \le 11$ $-12 \le l \le 11$	$-8 \le h \le 8$ $-8 \le k \le 8$ $-9 \le l \le 9$	$-6 \le h \le 2$ $-8 \le k \le 1$ $-19 \le l \le 18$
Complete to 2θ (%)	98.60	97.10	100.00	96.70	96.90	99.50	99.40
Data/restraints/parameters	2150/0/163	1843/0/156	1892/0/156	2322/0/192	1706/0/146	1864/0/155	1975/0/144
GooF (F^2)	1.026	1.034	1.051	1.017	1.039	0.870	1.027
R indices [I > 2σ(I)]	0.0447	0.0436	0.0427	0.0488	0.0391	0.0324	0.0414
wR_2 [I > 2σ(I)]	0.1249	0.1260	0.1191	0.1315	0.1339	0.1109	0.0671
R indices (all data)	0.0678	0.0654	0.0618	0.0733	0.0459	0.0371	0.1020
wR_2 (all data)	0.1415	0.1408	0.1314	0.1469	0.1255	0.1193	0.0787

Supporting information:

The Crystallographic information files are deposited to Cambridge Crystallographic Database and have the CCDC numbers 1417575-1417581.The proton NMR, spectra powder XRD patterns and the packing diagram of the cocrystals of quinoline-4-carbaldoxime with succinic acid and fumaric acid are available.

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