JOC The Journal of Organic Chemistry

Article

pubs.acs.org/joc

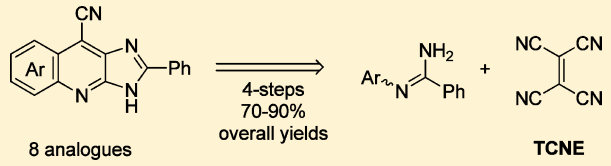
Reactions of Tetracyanoethylene with *N*′-Arylbenzamidines: A Route to 2-Phenyl-3*H*-imidazo[4,5-*b*]quinoline-9-carbonitriles

Styliana I. Mirallai, Maria Manoli, and Panayiotis A. Koutentis*

Department of Chemistry, University of Cyprus, P.O. Box 20537, 1678 Nicosia, Cyprus

Supporting Information

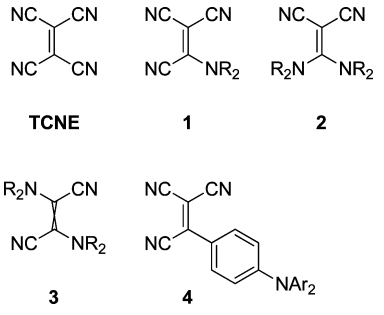
ABSTRACT: Eight 2-phenyl-3*H*-imidazo[4,5-*b*]quinoline-9-carbonitriles **15** are prepared in four steps from *N*′-arylbenzamidines **11** and tetracyanoethylene (TCNE) in ~70−90% yields. The transformation involves the initial formation of *N*-aryl-*N*′-(1,2,2-tricyanovinyl)benzamidines **12** in 87−99% yields, which in MeCN undergo a 5-exodig cyclization to give the 2-[1-aryl-5-imino-2-phenyl-1*H*-imidazol-4(5*H*)-ylidene]malononitriles **13** in 84−92% yields, while in MeOH the (*Z*)-2-[2-phenyl-4-(arylimino)-1*H*-imidazol-5(4*H*)-ylidene]malononitriles **14** are formed in 85−94% yields. The imidazoles **14** can also be prepared directly from imidazoles **13** via a Dimroth rearrangement in either neat MeOH or in DCM with DBU. Subsequent thermolysis of imidazoles **14** in diphenyl ether affords 2-phenyl-3*H*-imidazo[4,5-*b*]quinoline-9-carbonitriles **15** in near quantitative yields. Mechanistic rationale is provided for all transformations.



1. INTRODUCTION

Tetracyanoethylene (TCNE)[1,2] a cyanocarbon,[3] is the simplest of the percyano alkenes. It is highly electron-deficient and strongly electrophilic. Not surprisingly, TCNE can act as a powerful electron acceptor forming charge transfer complexes with various donors,[4,5] or it can participate in pericyclic chemistry as an electron-deficient dienophile in Diels−Alder reactions[4] or enophile in 2 + 2 cycloadditions.[6,7] Furthermore, it can act as an umpolung source of dicyanomethylene.[8−10] Its most common reaction is that of addition to its double bond and subsequent loss of the cyanide (tricyanovinylation). Direct addition to the nitrile can also occur but is less common.[11,12] The chemistry of TCNE has been extensively reviewed.[7,13−19]

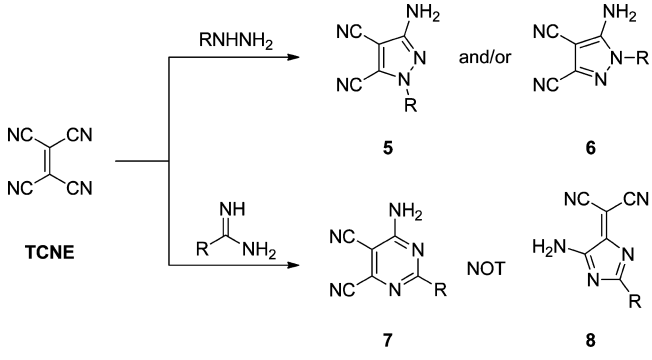
With primary or secondary aliphatic amines and with most primary and secondary aromatic amines, the reaction with TCNE gives *N*-tricyanovinylamines **1**, although with an excess of amine, 1,1-diamino-2,2-dicyanoethylenes **2**[13,20,21] or 1,2-diamino-1,2-dicyanoethylenes **3**[22] are formed. TCNE does not react with tertiary aliphatic amines, but it readily reacts with both tertiary and secondary aromatic amines, attacking the arene to give 4-tricyanovinyl-arylamines **4** via the initial formation of a 1:1 π complex.[21]



TCNE also reacts with a variety of bis-amino nucleophiles to give, after the initial addition to the double bond, intramolecular cyclizations typically on the vicinal nitrile that lead to various heterocyclic systems. For example, TCNE reacts with substituted hydrazines to give pyrazoles **5** and/or **6**,[11,12,23] or with 2-amidines to give 2-substituted 6-aminopyrimidine-4,5-dicarbonitriles **7**. The latter 6-exodig cyclization is somewhat surprising since a 5-exodig cyclization could in theory occur on the geminal nitrile to yield five-membered imidazoles of type **8** (Scheme 1).

To the best of our knowledge, only one report on the preparation of imidazolines from TCNE has appeared whereby *N*-methylamino functionalization of the intermediate tricyanovinylamine **9** led to a geminal (5-exodig) heterocyclization to

Scheme 1. Typical Reaction Products of TCNE with Hydrazines and Amidines

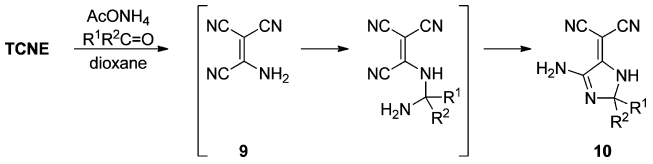


Received: June 24, 2013
Published: July 29, 2013

   dx.doi.org/10.1021/jo4013699 | *J. Org. Chem.* 2013, 78, 8655−8668

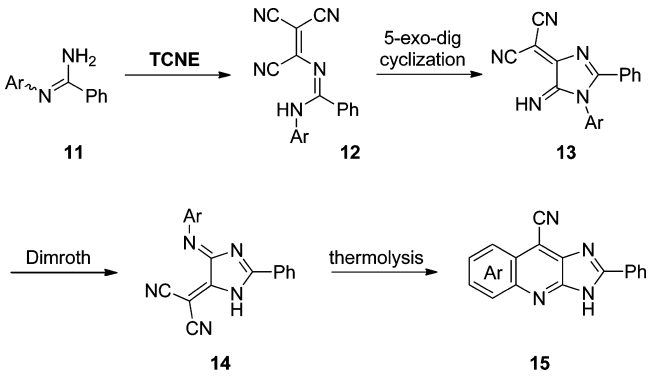
give 2-[5-amino-2,3-dihydro-4*H*-imidazol-4-ylidene]-malononitriles **10** (Scheme 2).[24]

Scheme 2. Formation of Imidazoles 10 from TCNE



In light of this and our interest in preparing cyano-substituted heteroarenes,[10,25−29] we report below our complementary study on the reaction of TCNE with readily available *N*′-arylbenzamidines **11**,[30] which affords (*Z*)-*N*-aryl-*N*′-(1,2,2-tricyanovinyl)benzamidines **12** that readily undergo a 5-exodig cyclization to the (imidazolylidene)-malononitriles **13**, which in two steps, via the Dimroth rearrangement product **14**, can be converted into 2-phenyl-3*H*-imidazo[4,5-*b*]quinoline-9-carbonitriles **15** (Scheme 3).

Scheme 3. Four-Step Conversion of TCNE and Benzamidines 11 into Imidazo[4,5-*b*]quinolines 15



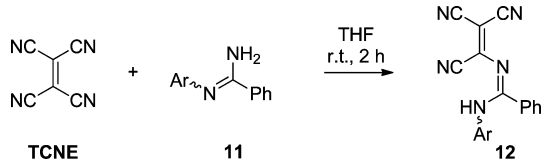
Previous syntheses of imidazo[4,5-*b*]quinolines include the one-pot Beckmann rearrangement of 3-acyl-2-(alkylamino)-quinolin-4-(1*H*)-ones,[31] the reductive cyclization of 5-(2-nitrobenzylidene)-3,5-dihydro-imidazol-4-ones,[32,33] from lithiated 3-aminoquinolines with nitriles,[34] and from 2,3-diaminoquinolines.[35] Several imidazo[4,5-*b*]quinolines behave as NO synthase inhibitors[35] or as analogues of antiviral polyhalogenated benzimidazole ribonucleosides;[36] furthermore, fused 3*H*-imidazo[4,5-*b*]quinoline-9-carbonitriles have been investigated as fluorescent dyes.[37]

2. RESULTS AND DISCUSSION

2.1. Preparation of *N*-Aryl-*N*′-(1,2,2-tricyanovinyl)-benzamidines 12. The reaction of *N*′-phenylbenzamidine **11a** with TCNE was investigated in a variety of solvents and temperatures, and in almost all cases, three products were observed in varying ratios by TLC: a colorless, a yellow, and an orange product **12a**, **13a**, and **14a**, respectively. The order of formation was determined (by TLC) to be first the colorless, then the yellow, and finally the orange colored compound. It was noted that the colorless product **12a** converted rapidly into the yellow product **13a** during a 2D TLC study; furthermore, polar protic solvents such as MeOH or EtOH strongly promoted the formation of the orange product **14a**. Both mass spectrometry and elemental analysis of these three products showed they were isomers with a molecular formula of $C_{18}H_{11}N_5$, indicating that an addition between TCNE and *N*′-phenylbenzamidine **11a** followed by loss of HCN had occurred.

Since silica promoted the conversion of the colorless compound into the isomeric yellow, we pursued a non-chromatographic work up to isolate a clean sample of the colorless compound **12a**: Treating *N*′-phenylbenzamidine **11a** with TCNE (1 equiv) in dry THF at ca. 20 °C led to the exclusive formation of the colorless compound **12a** (by TLC). By carefully evaporating the THF, redissolving the residue in a small quantity of Et_2O, and diluting with *n*-pentane, we were able to precipitate a microanalytically pure sample of the colorless product **12a** in 97% yield. The spectroscopic and analytical data (see Structure Elucidation Discussion for **12a** in Supporting Information) tentatively suggested the product to be *N*-phenyl-*N*′-(1,2,2-tricyanovinyl)benzamidine (**12a**), which could originate from simple substitution of one nitrile by the least sterically hindered *N*′-arylbenzamidine amino group. The reaction was general, and in total nine analogues were prepared (Table 1). Interestingly, where the benzamidines contained *N*′-

Table 1. Reaction of TCNE with *N*′-Arylbenzamidines 11



entries	TCNE (mmol)	Ar	yield **12** (%)
1	1.0	Ph	**12a** (97)
2	1.0	4-MeOC$_6$H$_4$	**12b** (98)
3	1.0	4-MeC$_6$H$_4$	**12c** (99)
4	1.0	4-FC$_6$H$_4$	**12d** (95)
5	1.2	4-ClC$_6$H$_4$	**12e** (95)
6	1.2	3,4-Cl$_2$C$_6$H$_3$	**12f** (92)
7	1.2	4-BrC$_6$H$_4$	**12g** (92)
8	1.2	4-IC$_6$H$_4$	**12h** (87)
9	1.2	4-O$_2$NC$_6$H$_4$	**12i** (88)

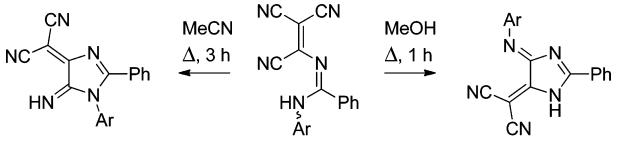
aryl substituents with either chloro, bromo, iodo or nitro substituents (entries 5−9), the reactions required a slight excess (1.2 equiv) of TCNE to come to completion.

2.2. Conversion of Tricyanovinylbenzamidines 12 into Imidazoles 13 and 14. Solutions of the tricyanovinylbenzamidine **12a** in DMF or DMSO at ca. 20 °C or heated to reflux in a range of solvents such as DCM, PhMe, or THF led to mixtures of both yellow and orange products **13a** and **14a**, respectively. Furthermore, treatment with either base (Hünig's base or DBU) or acid catalysis (TsOH·H_2O, H_2SO_4, or Lewis acids like $AlCl_3$, $FeCl_3$, $ZnCl_2$) gave more complex mixtures. Fortunately, simply heating a solution of the tricyanovinylbenzamidine **12a** in dry acetonitrile led to the formation of the yellow isomer **13a** in 88% yield, while in MeOH the orange isomer **14a** was formed in 92% yield. These conversions were generally high yielding for all nine analogues (Table 2).

The ^{13}C NMR spectroscopic data for both the yellow and orange isomers **13a** and **14a**, respectively, suggested one less nitrile group, which indicated a cyclization had occurred. As mentioned above, cyclizations to give either six-membered pyrimidines (via a 6-exodig cyclization) or five-membered imidazoles (via a 5-exodig) were possible (Scheme 1), however,

dx.doi.org/10.1021/jo4013699 | J. Org. Chem. 2013, 78, 8655−8668

Table 2. Conversion of Tricyanovinylbenzamidines 12 into Imidazoles 13 and 14



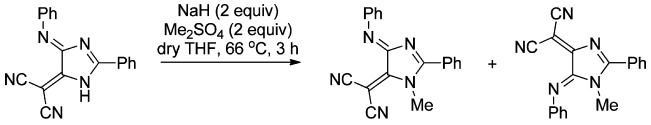
13 **12** **14**

entries	Ar	yield **13** (%)	yield **14** (%)
1	Ph	**13a** (88)	**14a** (92)
2	4-$MeOC_6H_4$	**13b** (89)	**14b** (91)
3	4-MeC_6H_4	**13c** (89)	**14c** (94)
4	4-FC_6H_4	**13d** (89)	**14d** (88)
5	4-ClC_6H_4	**13e** (87)	**14e**(86)
6	3,4-$Cl_2C_6H_3$	**13f** (87)	**14f** (90)
7	4-BrC_6H_4	**13g** (85)	**14g** (87)
8	4-IC_6H_4	**13h** (84)	**14h** (85)
9	4-$O_2NC_6H_4$	**13i** (92)	**14i** (93)

a study of the available spectroscopic data was inconclusive (see Structure Elucidation Discussion for **13a** and **14a** in Supporting Information). To identify these isomers, we collected single crystal X-ray data, which supported the yellow isomer to be 2-[5-imino-1,2-diphenyl-1*H*-imidazol-4(5*H*)-ylidene]-malononitrile (**13a**) (see Supporting Information, Figure S1) and the orange isomer to be (*Z*)-2-[2-phenyl-4-(phenylimino)-1*H*-imidazol-5(4*H*)-ylidene]malononitrile (**14a**) (see Supporting Information, Figure S2).

To study the chemistry of the imidazole **14a** further, it was *N*-methylated using methyl sulfate in dry THF. The products obtained were (*Z*)-2-[1-methyl-2-phenyl-4-(phenylimino)-1*H*-imidazol-5(4*H*)-ylidene]malononitrile (**16**) and (*Z*)-2-[1-methyl-2-phenyl-5-(phenylimino)-1*H*-imidazol-4(5*H*)-ylidene]-malononitrile (**17**) in 88 and 2% yields, respectively (Scheme 4).

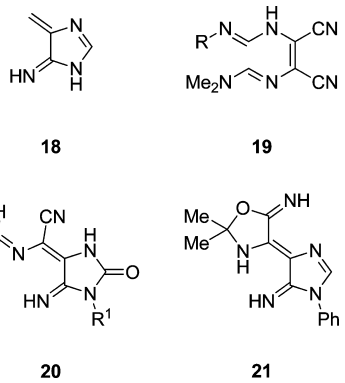
Scheme 4. *N*-Methylation of Imidazole 14a



14a **16** (88%) **17** (2%)

Unlike the nonmethylated imidazole **14a**, the ^1H and ^{13}C NMR spectra of both methylated isomers were well resolved, showing the expected eight quaternary, six CH, and one CH_3 carbon signals. The assigned regioselectivity for the methylation of the major isomer **16** was determined by single crystal X-ray spectroscopy (see Supporting Information, Figure S4), while 2D-NOESY ^1H NMR spectroscopy was used to support the assignment for the imidazole **17** (see Supporting Information). The UV−vis spectra for the *N*-methylated imidazoles **16** and **17**, which cannot suffer from prototautomerism, showed only minor solvatochromic effects (see Supporting Information, Figures S5 and S6).

Both the above imidazoles are examples of *ortho*-quinone methide imines (QMI's), which typically are reactive species and not readily isolated.[38] Not surprisingly, very few examples of this ring system have been reported: 4-Methylene-1*H*-imidazol-5(4*H*)-imines **18** have been proposed as possible intermediates in the conversion of (*Z*)-*N*^{1}-{1,2-dicyano-2-[(*N*,*N*-dimethylamino)methylamino]vinyl}formamidines **19** into purines or imino-pyrroles,[39] and as intermediates in the preparation of purine-*N*^{9}-acetic acids from HCN and glycine.[40] More recently, a series of prototautomerically closely related 4-imino-5-methyleneimidazolidin-2-ones **20** have been isolated and characterized.[41,42] Interestingly, the ^1H NMR in DMSO-d_6 indicated the imine NH was present as two broad singlets (δ_H 9.1−8.8 ppm) in a 1:1 ratio, which was attributed to *E*/*Z* isomers of the exocyclic methylene (cf. the ^1H NMR of imidazole **13a**). To the best of our knowledge, only one related X-ray structure has been reported, that of (*E*)-4-[5-imino-1-phenyl-1*H*-imidazol-4(5*H*)-ylidene]-2,2-dimethyloxazolidin-5-imine (**21**).[43]



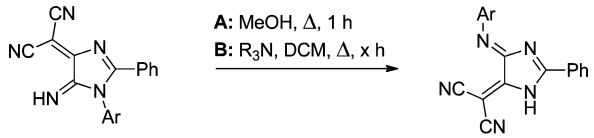
18 **19** **20** **21**

2.3. Dimroth Rearrangement of Imidazole 13 into Imidazole 14. A close analysis of the two imidazoles **13a** and **14a** indicated that the latter was probably the product of a Dimroth rearrangement of the former. Dimroth rearrangements are typically thermally induced or initiated by acids or bases.[44] Nevertheless, a pure sample of the imidazole **13a** dissolved in MeOH and left to stir at ca. 20 °C for 38 h was converted into the imidazole **14a** in high yield. The reaction time could be considerably shortened to 1 h by heating the reaction mixture to ca. 67 °C. Furthermore, in a nonprotic non-nucleophilic solvent such as DCM heated to ca. 40 °C, the conversion of imidazole **13a** into imidazole **14a** required the addition of base with DBU (1 equiv) giving the best results (Table 3). When DBU was replaced by pyridine, DMAP or lutidine or DABCO (1 equiv), the Dimroth rearrangement could not be driven to completion, while the use of trialkylamines, such as Et_3N (2−4 equiv) or Hünig's base (*i*-Pr_2NEt), led to no reaction. The reaction with DBU could also be carried out at ca. 20 °C, but the reaction time increased to 22 h, while the yield decreased to 84−86%. Finally, reducing the equivalents of DBU led to incomplete reactions (entry 1), while no significant advantage was observed in using more than 1 equiv (entry 3). Interestingly, the use of sterically hindered Barton's base also gave the imidazole **14a** in 91% (entry 4).

The rearrangement was irreversible since treating (*Z*)-2-[2-phenyl-4-(phenylimino)-1*H*-imidazol-5(4*H*)-ylidene]-malononitrile (**14a**) with either NaOH (0.5 mol %) in MeOH at ca. 67 °C or with DBU (1 equiv) in dry DCM at ca. 40 °C for 24 h led to no reaction. The reaction presumably is initiated by nucleophilic attack by either methanol/methoxide or even DBU, which can act as a nucleophile,[45] at the imidazole C-2 position, which is strongly electrophilic, activated by both the exocyclic ylidenemalononitrile and the imidazole imine, which have constructively aligned dipoles. Subsequent ring-opening via cleavage of the imidazole N(1)−C(2) bond affords a ring-

dx.doi.org/10.1021/jo4013699 | J. Org. Chem. 2013, 78, 8655−8668

Table 3. Dimroth Rearrangement of 2-(1-Aryl-5-imino-2-phenyl-1*H*-imidazol- 4(5*H*)-ylidene)malononitriles 13 into (*Z*)-2-[4-(Arylimino)-2- phenyl-4-1*H*-imidazol-5(4*H*)-ylidene]malononitriles 14



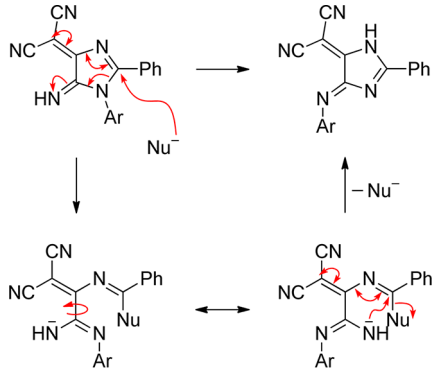
13 14

		cond B	yields **14** (%)	
entries	Ar	base (equiv), time (h)	cond A	cond B
1	Ph	DBU (0.5), 48	–	ir[a]
2	Ph	DBU (1), 4	–	**14a** (97)
3	Ph	DBU (2), 3	–	**14a** (96)
4	Ph	Barton's base (1),[b] 10	**14a** (99)	**14a** (91)
5	4-MeOC$_6$H$_4$	DBU (1), 4	**14b** (99)	**14b** (90)
6	4-MeC$_6$H$_4$	DBU (1), 4	**14c** (94)	**14c** (91)
7	4-FC$_6$H$_4$	DBU (1), 6	**14d** (98)	**14d** (92)
8	4-ClC$_6$H$_4$	DBU (1), 6	**14e** (98)	**14e** (92)
9	3,4-Cl$_2$C$_6$H$_3$	DBU (1), 6	**14f** (96)	**14f** (93)
10	4-IC$_6$H$_4$	DBU (1), 6	**14g** (94)	**14g** (88)
11	4-BrC$_6$H$_3$	DBU (1), 6	**14h** (95)	**14h** (91)
12	4-O$_2$NC$_6$H$_4$	DBU (1), 6	**14i** (95)	**14i** (95)

[a]ir = incomplete reaction. [b]2-*tert*-Butyl-1,1,3,3-tetramethylguanidine.

opened species that can rotate and undergo ring closure to afford the new imidazole **14** (Scheme 5).

Scheme 5. Mechanistic Rational for the Dimroth Rearrangement of Imidazoles 13



2.4. Thermal Behavior Studies of Imidazoles 13 and 14. The thermal behavior of both imdiazoles **13a** and **14a** was also investigated: Differential scanning calorimetry (DSC) studies under an argon atmosphere showed that the imidazole **13a** immediately decomposed after melting. On heating a bulk sample under argon atmosphere at ca. 220 °C for 20 min, a reaction mixture was obtained, from which the imidazole **14a** was isolated in low yield (34%) together with two new products 2-phenyl-6-(phenylamino)pyrimidine-4,5-dicarbonitrile (**22**) (11%) and traces of 2-phenyl-3*H*-imidazo[4,5-*b*]quinoline-9-carbonitrile (**15a**) (see Structural Elucidation Discussion of **15a** and **22** in Supporting Information).

Tentatively, pyrimidine **22** can form from imidazole **13a** in three steps: First imidazole **13a** ring opens to give the tricyanovinylamidine intermediate **12a**, which subsequently undergoes a 6-exodig heterocyclization on the vicinal nitrile to give 6-imino-1,2-diphenyl-1,6-dihydropyrimidine-4,5-dicarbonitrile (**23**), which under the reaction conditions Dimroth rearranges to the observed pyrimidine **22** (Scheme 6). Unfortunately, no trace of the pyrimidine **23** could be identified and isolated from the reaction mixture.

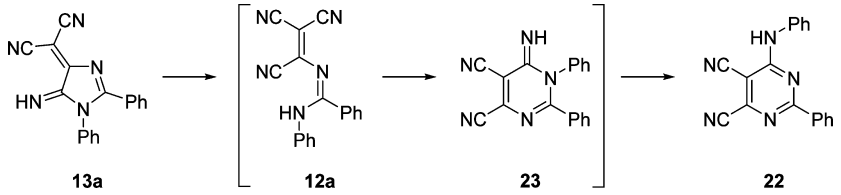
Surprisingly, complex reaction mixtures were also obtained when the reaction was carried out using inert solvents such as toluene, xylene, chlorobenzene, or diphenyl ether at reflux, while in benzene heated to reflux the yellow imidazole **13a** was stable.

As for 2-phenyl-3*H*-imidazo[4,5-*b*]quinoline-9-carbonitrile (**15a**), based on the carbon−nitrogen connectivity, we tentatively suggest that the product could have formed from imidazole **14a** via an electrocyclic ring closure and subsequent loss of HCN (Scheme 7).

In light of this, we carried out a DSC study of a pure sample of the imidazole **14a** that showed only an exothermic transition (onset 255.8 °C peak 256.7 °C). On cooling to ca. 20 °C, a TLC analysis of the contents of this DSC pan revealed only one product, compound **15a**. Subsequent thermolysis of the imidazole **14a** in diphenyl ether at ca. 280 °C, for 4 h protected from moisture with $CaCl_2$ drying tube, gave compound **15a** quantitatively. The reaction temperature could be lowered to 215 °C without affecting the product yield, although this led to longer reaction times (26 h). In boiling benzene or toluene no 2-phenyl-3*H*-imidazo[4,5-*b*]quinoline-9-carbonitrile (**15a**) was obtained, while chlorobenzene led to an incomplete reaction even after 2 d. The reaction was general, and nearly all of the imidazoles **14** could be converted into the their corresponding 2-phenyl-3*H*-imidazo[4,5-*b*]quinoline-9-carbonitriles **15** (Table 4).

Worthy of note was that the imidazoles **14** supporting electron-donating substituents on the arylimino group (entries 5 and 6) reacted faster than analogues supporting electron-withdrawing groups (entries 7 and 8). Furthermore, the thermolysis of the unsymmetrically substituted dichlorophenyl-imidazole **14f** (entry 9) gave as expected the two possible isomeric products: 6,7-dichloro-2-phenyl-3*H*-imidazo[4,5-*b*]-quinoline-9-carbonitrile (**15f**) and 7,8-dichloro-2-phenyl-1*H*-imidazo[4,5-*b*]quinoline-9-carbonitrile (**15g**) in 84 and 12% yields, respectively, where the product ratio presumably reflects the steric demands for the respective cyclizations. Disappointingly, thermolysis of the nitrophenyl analogue (entry 12) led to

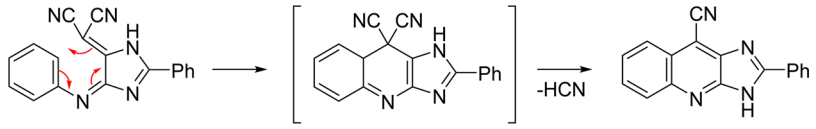
Scheme 6. Proposed Route for the Formation of Pyrimidine 22



13a 12a 23 22

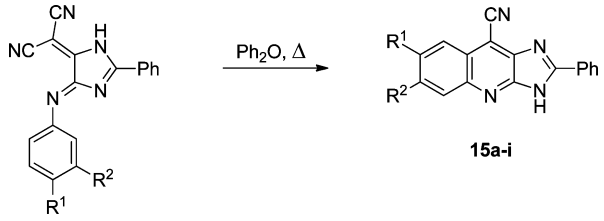
dx.doi.org/10.1021/jo4013699 | *J. Org. Chem.* 2013, 78, 8655−8668

Scheme 7. Proposed Mechanism for the Formation of Imidazo[4,5-*b*]quinoline 15a



14a 15a

Table 4. Thermolysis of (*Z*)-2-[4-(Arylimino)-2-phenyl-4-1*H*-imidazol-5(4*H*)-ylidene]malononitriles 14 to Give 2-Phenyl-3*H*-imidazo[4,5-*b*]quinoline-9-carbonitriles 15



14a-i 15a-i

entries	R^1	R^2	temp (°C)	time (h)	yields (%)
1	H	H	280	4	**15a** (100)
2	H	H	260	4	**15a** (99)
3	H	H	240	18	**15a** (99.5)
4	H	H	215	26	**15a** (99)
5	MeO	H	280	2	**15b** (99)
6	Me	H	280	2	**15c** (99)
7	F	H	280	6	**15d** (99)
8	Cl	H	280	6	**15e** (98)
9	Cl	Cl	280	6	**15f** (84)[a]
10	Br	H	280	4	**15h** (98)
11	I	H	280	4	**15i** (98)
12	O_2N	H	280	6	[b]

[a]7,8-Dichloro-2-phenyl-1*H*-imidazo[4,5-*b*]quinoline-9-carbonitrile (**15g**) was also isolated as a side product (12%). [b]A complex and unresolvable reaction mixture was observed.

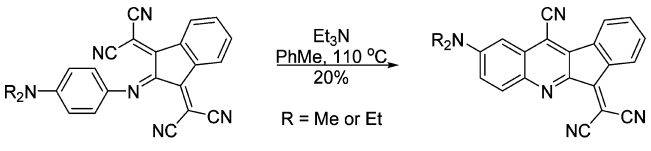
a very complex reaction mixture (by TLC), which could not be resolved.

While there are many examples of the preparation of quinolines via electrocyclic ring closures followed by elimination of a leaving group to regain aromaticity,[46−52] there are very few examples that afford quinolines fused to five-[53,54] and six-membered rings,[55,56] and only one example involving an ylidenemalononitrile; cyclization of 2,2′-(2-{[4-(dialkylamino)-phenyl]-imino}-1*H*-indene-1,3(2*H*)-diylidene)dimalononitriles **24** affords 2-[2-(dialkylamino)-11-cyano-6*H*-indeno[2,1-*b*]-quinolin-6-ylidene)malononitriles **25** in low yields (Scheme 8).[57]

2.5. Preparation of *N*-Methylated 2-Phenyl-3*H*-imidazo[4,5-*b*]quinoline-9-carbonitriles. The regioselectivity of 2-phenyl-3*H*-imidazo[4,5-*b*]quinoline-9-carbonitrile (**15a**) towards *N*-methylation was investigated. As such, methylation of 2-phenyl-3*H*-imidazo[4,5-*b*]quinoline-9-carbonitrile (**15a**) using NaH (2 equiv) and dimethyl sulfate (2 equiv) in dry THF at ca. 66 °C gave two products: 3-methyl-2-phenyl-3*H*-imidazo[4,5-*b*]quinoline-9-carbonitrile (**27**) and 4-methyl-2-phenyl-4*H*-imidazo[4,5-*b*]quinoline-9-carbonitrile (**28**) in 95 and 1% yields, respectively (Scheme 9). No trace of 1-methyl-2-phenyl-1*H*-imidazo[4,5-*b*]quinoline-9-carbonitrile (**26**) was observed. The regioselectivity of the methylations was supported by 2D-NOESY ^{1}H NMR experiments (see Supporting Information).

Since both the methylated imidazoles (*Z*)-2-[1-methyl-2-phenyl-4-(phenylimino)-1*H*-imidazol-5(4*H*)-ylidene]-malononitrile (**16**) and (*Z*)-2-[1-methyl-2-phenyl-5-(phenyl-imino)-1*H*-imidazol-4(5*H*)-ylidene]malononitrile (**17**) were in our possession, these were also independently thermolyzed to give 1-methyl-2-phenyl-1*H*-imidazo[4,5-*b*]quinoline-9-carbonitrile (**26**) and 3-methyl-2-phenyl-3*H*-imidazo[4,5-*b*]-quinoline-9-carbonitrile (**27**) in high yields, respectively (Scheme 10).

Scheme 8. Example of a Quinoline Synthesis via Electrocylic Ring Closure



24 25

3. CONCLUSIONS

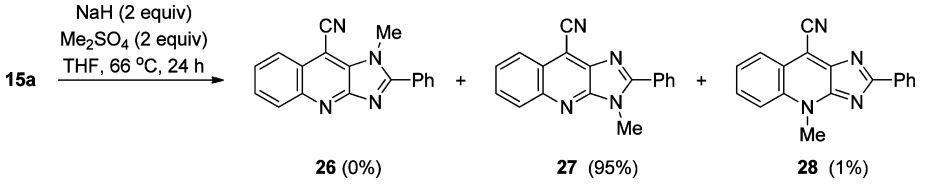
The reaction of TCNE and *N*′-arylbenzamidines affords a densely functionalized adduct, which on standing or gentle heating undergoes a 5-exodig cyclization to give the novel imidazoles **13**. These in turn, in neat refluxing MeOH or in DCM with DBU, suffer Dimroth rearrangements to give imidazoles **14**. The latter compounds readily undergo thermal mediated electrocyclic ring closures to give 3*H*-imidazo[4,5-*b*]-quinolines **15** in almost quantitative yields. As such, the synthetic route outlined above affords a new 4-step but high yielding route to this useful ring system via readily available TCNE and *N*′-arylbenzamidines.

4. EXPERIMENTAL SECTION

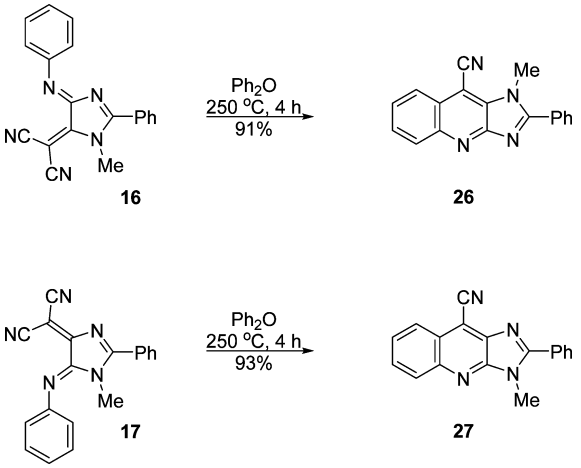
4.1. General Methods and Materials. Reactions were protected from atmospheric moisture by $CaCl_2$ drying tubes. All reaction mixtures and column eluents were monitored by TLC using commercial glass-backed thin-layer chromatography (TLC) plates (Kieselgel 60 F_{254}). The plates were observed under UV light at 254 and 365 nm. The technique of dry flash chromatography[58] was used throughout for all non-TLC scale chromatographic separations using silica gel 60 (less than 0.063 mm). Melting points were determined using a Koefler-Hotstage microscope apparatus. Decomposition points (decomp.) were determined using a DSC with samples hermetically sealed in aluminum pans under an argon atmosphere, using heating rates of 5 °C/min. Solvents used for recrystallization are indicated after the melting point. Inflections in the UV spectra are identified by the abbreviation "inf". IR spectra were recorded using a Ge ATR accessory, and strong, medium, and weak peaks are represented by s, m, and w, respectively. ^{1}H and ^{13}C NMR spectra were recorded at 500 and 125 MHz, respectively. Deuterated solvents were used for homonuclear lock, and the signals are referenced to the deuterated solvent peaks. DEPT135 or APT NMR studies identified quaternary and tertiary carbons, which are indicated by (s) and (d) notations, respectively.

dx.doi.org/10.1021/jo4013699 | J. Org. Chem. 2013, 78, 8655−8668

Scheme 9. *N*-Methylation of Imidazo[4,5-*b*]quinoline-9-carbonitrile 15a



Scheme 10. Thermolysis of *N*-Methylated Imidazoles 16 and 17



Deuterated solvents were used for homonuclear lock, and the signals are referenced to the deuterated solvent peaks. Low resolution (EI) mass spectra were recorded on a GC−MS with direct inlet probe. Tetracyanoethylene (TCNE)[59] and the *N*′-arylbenzamidines **11a**−**i**[30] were prepared according to literature procedures.

4.2. Reaction of *N*′-Arylbenzamidines with Tetracyanoethylene (TCNE). *4.2.1. N*′*-Phenyl-N-(1,2,2-tricyanovinyl)-benzamidine (**12a**) (Typical Procedure, See Table 1).* To a stirred solution of tetracyanoethylene (128 mg, 1 mmol) in dry THF (5 mL), at ca. 20 °C and protected with $CaCl_2$ drying tube, was added a solution of *N*′-phenylbenzamidine (**11a**) (196 mg, 1 mmol) in dry THF (5 mL). The mixture was then left to stir at ca. 20 °C for 2 h, after which time the reaction was complete (by TLC), and the solvent was evaporated under reduced pressure (at <25 °C). The residue was then dissolved in Et_2O (2 mL), and after cooling to 0 °C, *n*-pentane (40 mL) was added and triturated to form the precipitated title compound **12a** (288.7 mg, 97%) as colorless plates: mp (DSC) onset 135.7 °C, peak max. 139.1 °C, decomp. onset 140.8 °C peak max. 141.0 °C (from *n*-pentane/THF); (found C, 72.61; H, 3.66; N, 23.45. $C_{18}H_{11}N_5$ requires C, 72.72; H, 3.73; N, 23.56%); R_f 0.51 (DCM/Et_2O, 95:05); λ_{max}(DCM)/nm 241 (log ε 4.29), 280 inf (3.74); ν_{max}/cm^{-1} 3258m (NH), 3064w (Ar CH), 2826w, 2201w (C≡N), 1692s, 1670w, 1651w, 1603m, 1593m, 1562s, 1557s, 1493m, 1454w, 1445m, 1375m, 1323m, 1315m, 1310m, 1285m, 1263m, 1184w, 1159w, 1126s, 1071m, 1039w, 1030m, 1007m, 1001w, 941w, 935w, 918m, 910m, 881m, 847w, 814w, 783s, 729m; δ_H (500 MHz; $CDCl_3$) 8.04 (1H, br s, N*H*), 7.54−7.50 (3H, m, Ar *H*), 7.49−7.46 (3H, m, Ar *H*), 7.32 (2H, dd, *J* 8.0, 8.0, Ar *H*), 7.17 (2H, br s, Ar *H*); δ_C (125 MHz; $CDCl_3$) 168.5 (s), 161.8 (s), 132.84 (s), 132.81 (d), 130.8 (d), 130.4 (d), 129.3 (d), 128.6 (d), 127.8 (d), 126.4 (s), 112.5 (s, *C*≡N), 108.4 (s, *C*≡N), 108.0 (s, *C*≡N), 66.9 [s, $C(CN)_2$]; *m*/*z* (MALDI-TOF) 299 (MH^+ + 1, 1%), 298 (MH^+, 8), 295, (3), 282 (100), 261 (3), 260 (7), 259 (8), 180 (18).

4.2.2. N′*-(4-Methoxyphenyl)-N-(1,2,2-tricyanovinyl)benzamidine (**12b**).* Similar treatment of TCNE (128 mg, 1 mmol) with *N*′-(4-methoxyphenyl)benzamidine (**11b**) (226 mg, 1 mmol) gave the title compound **12b** (319.3 mg, 98%) as colorless plates: mp 68.8−69.5 °C (from *n*-pentane/THF); (found C, 69.62; H, 4.18; N, 21.40. $C_{19}H_{13}N_5O$ requires C, 69.71; H, 4.00; N, 21.39%); R_f 0.56 (DCM/Et_2O, 95:05); λ_{max}(DCM)/nm 237 (log ε 4.51), 275 inf (3.96); ν_{max}/cm^{-1} 3269m (NH), 3063w (Ar CH), 2899w, 2843w, 2226w (C≡N), 1695w, 1684w, 1653w, 1636w, 1607w, 1593w, 1568w, 1539w, 1512s, 1466w, 1447w, 1420w, 1387w, 1321m, 1312m, 1302m, 1254s, 1180w, 1171w, 1125m, 1065w, 1028w, 910w, 841m, 812w, 799w, 775w, 746w; δ_H (500 MHz; $CDCl_3$) NH resonance missing, 7.50−7.48 (3H, m, Ar *H*), 7.33 (2H, dd, *J* 8.0, 8.0, Ar *H*), 7.08 (2H, br s, Ar *H*), 6.99 (2H, d, *J* 8.0, Ar *H*), 3.85 (3H, s, OCH_3); δ_C (125 MHz; $CDCl_3$) 168.7 (s), 162.4 (s), 160.7 (s), 132.7 (d), 129.3 (d), 129.2 (d), 128.6 (d), 126.5 (s), 125.0 (s), 116.0 (d), 112.5 (s, *C*≡N), 108.5 (s, *C*≡N), 108.0 (s, *C*≡N), 66.7 [s, $C(CN)_2$], 55.6 (q, OCH_3); *m*/*z* (MALDI-TOF) 331 (MH^+ + 2, 17%), 331 (MH^+ + 1, 3), 328 (MH^+, 2), 312 (8), 227 (29), 211 (12), 210 (100), 181 (13), 71 (8).

4.2.3. N′*-(p-Tolyl)-N-(1,2,2-tricyanovinyl)benzamidine (**12c**).* Similar treatment of TCNE (128 mg, 1 mmol) with *N*′-(*p*-tolyl)-benzamidine (**11c**) (210 mg, 1 mmol) gave the title compound **12c** (309.3 mg, 99%) as colorless plates: mp (DSC) onset 149.4 °C, peak max. 151.0 °C, decomp. onset 152.2 °C peak max. 153.6 °C (from *n*-pentane/THF); (found C, 73.33; H, 4.25; N, 22.58. $C_{19}H_{13}N_5$ requires C, 73.30; H, 4.21; N, 22.49%); R_f 0.59 (DCM/Et_2O, 95:05); λ_{max}(DCM)/nm 239 (log ε 4.31), 277 inf (3.80); ν_{max}/cm^{-1} 3252m (NH), 2808w, 2517w, 2199w (C≡N), 1694m, 1682m, 1601m, 1591m, 1560s, 1510m, 1497w, 1470w, 1447m, 1385m, 1379m, 1323s, 1315m, 1296s, 1265m, 1213w, 1179w, 1128s, 1072m, 1065m, 1040w, 1030m, 1022w, 1007m, 980w, 966w, 945w, 933w, 912m, 880m, 845w, 830m, 810m, 806w, 798w, 781m, 746m; δ_H (500 MHz; $CDCl_3$) 8.00 (1H, s, N*H*), 7.50−7.46 (3H, m, Ar *H*), 7.34−7.29 (4H, m, Ar *H*), 7.03 (2H, br s, Ar *H*), 2.42 (3H, s, CH_3); δ_C (125 MHz; $CDCl_3$) 168.5 (s), 162.1 (s), 140.8 (s), 132.8 (d), 131.4 (d), 130.1 (s), 129.3 (d), 128.6 (d), 127.5 (d), 126.5 (s), 112.5 (s, *C*≡N), 108.4 (s, *C*≡N), 108.0 (s, *C*≡N), 66.8 [s, $C(CN)_2$], 21.3 (q, CH_3); *m*/*z* (MALDI-TOF) 312 (MH^+, 4%), 296 (7), 275 (3), 247 (4), 194 (100), 105 (3), 91 (9).

4.2.4. N′*-(4-Fluorophenyl)-N-(1,2,2-tricyanovinyl)benzamidine (**12d**).* Similar treatment of TCNE (128 mg, 1 mmol) with *N*′-(4-fluorophenyl)benzamidine (**11d**) (214 mg, 1 mmol) gave the title compound **12d** (299.6 mg, 95%) as colorless plates: mp (DSC) onset 146.0 °C, peak max. 148.2 °C, decomp. onset 149.1 °C peak max. 150.4 °C (from *n*-pentane/THF); (found C, 68.36; H, 3.33; N, 22.19. $C_{18}H_{10}FN_5$ requires C, 68.57; H, 3.20; N, 22.21%); R_f 0.49 (DCM/Et_2O, 95:05); λ_{max}(DCM)/nm 244 (log ε 4.23), 276 inf (3.76); ν_{max}/cm^{-1} 3258m (NH), 2814w, 2521w, 2203w (C≡N), 1697m, 1686m, 1605m, 1593m, 1562m, 1508s, 1447m, 1418w, 1379m, 1323m, 1314m, 1292m, 1287m, 1265w, 1238m, 1223m, 1184w, 1155m, 1126s, 1096w, 1071m, 1042w, 1030m, 1008m, 982w, 943w, 933w, 916m, 883m, 849m, 841m, 822w, 802w, 783m, 750m; δ_H (500 MHz; $CDCl_3$) 8.02 (1H, br s, N*H*), 7.51 (1H, dd, *J* 7.5, 7.5, Ar *H*), 7.46 (2H, d, *J* 8.5, Ar *H*), 7.35 (2H, dd, *J* 8.0, 8.0, Ar *H*), 7.21−7.19 (4H, m, Ar *H*); δ_C (125 MHz; $CDCl_3$) 168.5 (s), 163.1 (s, $^1J_{CF}$ 251.5, CF), 161.8 (s), 133.0 (d), 129.9 (d, $^3J_{CF}$ 8.9, CHCHCF), 129.2 (d), 128.8 (d), 126.2 (s), 118.1 (d, $^2J_{CF}$ 22.4, CHCF), 112.3 (s, C≡N), 108.3 (s, C≡N), 108.0 (s, C≡N), 68.0 [s, $C(CN)_2$]; *m*/*z* (MALDI-TOF) 316 (MH^+, 3%), 300 (5), 198 (100), 105 (4).

4.2.5. N′*-(4-Chlorophenyl)-N-(1,2,2-tricyanovinyl)benzamidine (**12e**).* Similar treatment of TCNE (154 mg, 1.2 mmol) with *N*′-(4-chlorophenyl)benzamidine (**11e**) (231 mg, 1 mmol) gave the title compound **12e** (314.6 mg, 95%) as colorless plates: mp (DSC) onset 146.8 °C, peak max. 148.4 °C, decomp. onset 150.3 °C peak max. 151.9 °C (from *n*-pentane/THF); (found C, 64.97; H, 2.93; N, 21.17. $C_{18}H_{10}ClN_5$ requires C, 65.17; H, 3.04; N, 21.11%); R_f 0.41 (DCM/

dx.doi.org/10.1021/jo4013699 | J. Org. Chem. 2013, 78, 8655−8668

Et_2O, 95:05); λ_{max}(DCM)/nm 242 (log ε 4.33), 277 inf (3.81); ν_{max}/cm^{-1} 3254w (NH), 2525w, 2201w (C≡N), 1692m, 1603m, 1593m, 1562m, 1493s, 1447m, 1408w, 1383w, 1323m, 1304m, 1294m, 1277w, 1265w, 1188w, 1128m, 1094m, 1071w, 1030w, 1016m, 945w, 939w, 930w, 912m, 880w, 837m, 822w, 806w, 781m, 760w, 739w; δ_H (500 MHz; $CDCl_3$) 8.05 (1H, s, N*H*), 7.54−7.49 (3H, m, Ar *H*), 7.46 (2H, d, *J* 8.5, Ar *H*), 7.36 (2H, dd, *J* 7.8, 7.8, Ar *H*), 7.11 (2H, br s, Ar *H*); δ_C (125 MHz; $CDCl_3$) 168.3 (s), 161.5 (s), 136.6 (s), 133.0 (d), 131.3 (s), 131.1 (d), 129.2 (d), 129.1 (d), 128.8 (d), 126.1 (s), 112.3 (s, *C*≡N), 108.3 (s, *C*≡N), 107.9 (s, *C*≡N), 66.9 [s, *C*$(CN)_2$]; *m*/*z* (MALDI-TOF) 334 (MH^+ + 2, 3%), 332 (MH^+, 1), 318 (12), 316 (55), 294 (34), 231 (30), 216 (29), 214 (100).

*4.2.6. N′-(3,4-Dichlorophenyl)-N-(1,2,2-tricyanovinyl)-benzamidine (**12f**).* Similar treatment of TCNE (154 mg, 1.2 mmol) with *N′*-(3,4-dichlorophenyl)benzamidine (**11f**) (265 mg, 1 mmol) gave the title compound **12f** (335.1 mg, 92%) as colorless plates: mp (DSC) onset 151.5 °C, peak max. 155.5 °C, decomp. onset 157.0 °C peak max. 158.1 °C (from *n*-pentane/THF); (found C, 58.83; H, 2.59; N, 19.21. $C_{18}H_9Cl_2N_5$ requires C, 59.04; H, 2.48; N, 19.12%); R_f 0.46 (DCM/Et_2O, 95:05); λ_{max}(DCM)/nm 244 (log ε 4.67), 278 inf (4.13); ν_{max}/cm^{-1} 3254m (NH), 2795w, 2533w, 2259w and 2197w (C≡N), 1703w, 1688s, 1605m, 1593m, 1564m, 1497w, 1474s, 1447w, 1406w, 1393w, 1370w, 1327m, 1304s, 1277m, 1242w, 1128s, 1086w, 1076w, 1065m, 1036m, 1011w, 982w, 957w, 932w, 912m, 887w, 874m, 847w, 829m, 818w, 797m, 781s, 745m; δ_H (500 MHz; $CDCl_3$) 8.12 (1H, br s, N*H*), 7.58 (1H, d, *J* 8.5 Ar *H*), 7.55 (1H, dd, *J* 7.5, 7.5, Ar *H*), 7.47 (2H, d, *J* 7.5, Ar *H*), 7.38 (2H, dd, *J* 7.8, 7.8, Ar *H*), 7.33 (1H, br s, Ar *H*), 6.99 (1H, br s, Ar *H*); δ_C (125 MHz; $CDCl_3$) 167.8 (s), 160.8 (s), 135.4 (s), 135.2 (s), 133.2 (d), 132.6 (d), 132.0 (s), 129.5 (d), 129.2 (d), 129.0 (d), 127.1 (d), 125.8 (s), 112.1 (s, *C*≡N), 108.2 (s, *C*≡N), 107.9 (s, *C*≡N), 67.2 [s, *C*$(CN)_2$]; *m*/*z* (MALDI-TOF) 368 (MH^+ + 2, 3%), 366 (MH^+, 2), 350 (8), 329 (4), 303 (2), 250 (65), 248 (100), 207 (8), 199 (9), 181 (7), 127 (8), 111 (22), 109 (4), 105 (15), 97 (5), 88 (13), 77 (2).

*4.2.7. N′-(4-Bromophenyl)-N-(1,2,2-tricyanovinyl)benzamidine (**12g**).* Similar treatment of TCNE (154 mg, 1.2 mmol) with *N′*-(4-bromophenyl)benzamidine (**11g**) (275 mg, 1 mmol) gave the title compound **12g** (346.0 mg, 92%) as colorless plates: mp 85.2−86.6 °C (from *n*-pentane/THF); (found C, 57.39; H, 2.72; N, 18.62. $C_{18}H_{10}BrN_5$ requires C, 57.47; H, 2.68; N, 18.62%); R_f 0.54 (DCM/Et_2O, 95:05); λ_{max}(DCM)/nm 242 (log ε 4.48), 279 inf (3.87); ν_{max}/cm^{-1} 3277w (NH), 3099w and 3063w (Ar CH), 2974w, 2899w, 2255w and 2201w (C≡N), 1692m, 1653w, 1609m, 1595m, 1568m, 1489s, 1449m, 1402w, 1379m, 1311s, 1296m, 1273w, 1249w, 1202w, 1182w, 1125s, 1072s, 1030w, 1013s, 937w, 910m, 837s, 808w, 794w, 777s, 750m; δ_H (500 MHz; $CDCl_3$) 8.05 (1H, br s, N*H*), 7.64 (2H, d, *J* 8.0 Ar *H*), 7.52 (1H, dd, *J* 7.3, 7.3, Ar *H*), 7.46 (2H, d, *J* 8.5, Ar *H*), 7.36 (2H, dd, *J* 7.8, 7.8, Ar *H*), 7.04 (2H, d, *J* 5.5, Ar *H*); δ_C (125 MHz; $CDCl_3$) 168.3 (s), 161.4 (s), 134.1 (d), 133.0 (d), 131.8 (s), 129.3 (d), 129.2 (d), 128.8 (d), 126.1 (s), 124.6 (s), 112.3 (s, *C*≡N), 108.3 (s, *C*≡N), 107.9 (s, *C*≡N), 66.9 [s, *C*$(CN)_2$]; *m*/*z* (MALDI-TOF) 378 (MH^+ + 2, 2%), 376 (MH^+, 1), 362 (4), 360 (5), 312 (2), 260 (90), 258 (100), 181 (26), 111 (3), 71 (27).

*4.2.8. N′-(4-Iodophenyl)-N-(1,2,2-tricyanovinyl)benzamidine (**12h**).* Similar treatment of TCNE (154 mg, 1.2 mmol) with *N′*-(4-iodophenyl)benzamidine (**11h**) (322 mg, 1 mmol) gave the title compound **12h** (366.0 mg, 87%) as colorless plates: mp 89.5−91.2 °C (from *n*-pentane/THF); (found C, 51.22; H, 2.31; N, 16.68. $C_{18}H_{10}IN_5$ requires C, 51.08; H, 2.38; N, 16.55%); R_f 0.59 (DCM/Et_2O, 95:05); λ_{max}(DCM)/nm 246 (log ε 4.51), 278 inf (3.94); ν_{max}/cm^{-1} 3273w (NH), 3067w (Ar CH), 2964w, 2903w, 2255w and 2201w (C≡N), 1692m, 1609m, 1593m, 1566m, 1493m, 1487s, 1449m, 1398w, 1375m, 1319s, 1312s, 1250w, 1182w, 1125s, 1067m, 1028w, 1009s, 937w, 910m, 849m, 835m, 777m, 748m; δ_H (500 MHz; $CDCl_3$) 8.06 (1H, br s, N*H*), 7.84 (2H, d, *J* 8.0, Ar *H*), 7.52 (1H, dd, *J* 7.5, 7.5, Ar *H*), 7.46 (2H, d, *J* 8.5, Ar *H*), 7.36 (2H, dd, *J* 7.8, 7.8, Ar *H*), 6.90 (2H, d, *J* 5.5, Ar *H*); δ_C (125 MHz; $CDCl_3$) 168.3 (s), 161.4 (s), 140.1 (d), 133.0 (d), 132.6 (s), 129.4 (d), 129.2 (d), 128.8 (d), 126.1 (s), 112.3 (s, *C*≡N), 108.3 (s, *C*≡N), 107.9 (s, *C*≡N), 96.3 (s), 66.9 [s, *C*$(CN)_2$]; *m*/*z* (MALDI-TOF) 426 (MH^+ + 2, 1%), 424 (MH^+, 2), 408 (2), 387 (2), 386 (2), 323 (55), 307 (10), 306 (100), 180 (30), 179 (11), 105 (9).

*4.2.9. N′-(4-Nitrophenyl)-N-(1,2,2-tricyanovinyl)benzamidine (**12i**).* Similar treatment of TCNE (154 mg, 1.2 mmol) with *N′*-(4-nitrophenyl)benzamidine (**11i**) (241 mg, 1 mmol) gave the title compound **12i** (301.0 mg, 88%) as colorless plates: mp (DSC) onset 149.9 °C, peak max. 152.9 °C, decomp. onset 155.1 °C peak max. 156.1 °C (from *n*-pentane/THF); (found C, 62.97; H, 2.84; N, 24.55. $C_{18}H_{10}N_6O_2$ requires C, 63.16; H, 2.94; N, 24.55%); R_f 0.64 (DCM/Et_2O, 95:05); λ_{max}(DCM)/nm 248 (log ε 4.29), 282 inf (4.03); ν_{max}/cm^{-1} 3296w (NH), 3119w and 3082w (Ar CH), 2808w, 2627w, 2260w and 2201w (C≡N), 1757w, 1692m, 1612m, 1593m, 1574m, 1524s, 1497m, 1474w, 1449w, 1420w, 1387m, 1348s, 1321m, 1312m, 1292w, 1234w, 1184w, 1176w, 1144m, 1132m, 1109w, 1074w, 1028w, 1011w, 1001w, 939w, 926w, 912m, 856m, 837m, 822w, 771m, 754m, 741w; δ_H (500 MHz; $CDCl_3$) NH resonance missing, 8.35 (2H, d, *J* 8.5, Ar *H*), 7.55 (1H, dd, *J* 7.3, 7.3 Ar *H*), 7.43 (2H, d, *J* 8.5, Ar *H*), 7.39−7.35 (4H, m, Ar *H*); δ_C (125 MHz; $CDCl_3$) one C (s) peak missing 149.0 (s), 148.1 (s), 138.5 (s), 133.3 (d), 129.1 (d), 129.0 (d), 128.7 (d), 125.9 (d), 125.8 (s), 112.0 (s, *C*≡N), 108.1 (s, *C*≡N), 107.8 (s, *C*≡N), 68.0 [s, *C*$(CN)_2$]; *m*/*z* (MALDI-TOF) 344 (MH^+ + 1, 1%), 343 (MH^+, 2), 340 (5), 327 (100), 304 (41), 242 (11), 225 (99), 179 (48).

4.3. Conversion of *N*-Aryl-*N*-(1,2,2-tricyanovinyl)-benzamidines into 2-[5-Imino-1-aryl-2-phenyl-1*H*-imidazol-4(5*H*)-ylidene]malononitriles. *4.3.1. 2-[5-Imino-1,2-diphenyl-1H-imidazol-4(5H)-ylidene]malononitrile (**13a**) (Typical Procedure, See Table 2).* A stirred solution of *N′*-phenyl-*N*-(1,2,2-tricyanovinyl)-benzamidine (**12a**) (29.7 mg, 0.1 mmol) in dry acetonitrile (1 mL) was heated at ca. 82 °C for 3 h and chromatography (DCM) of the residue gave the title compound **13a** (26.2 mg, 88%) as yellow prisms: mp (DSC) onset 195.6 °C, peak max. 201.3 °C, decomp. onset 205.2 °C peak max. 207.9 °C (from *n*-pentane/THF, 90:10); (found C, 72.61; H, 3.66; N, 23.45. $C_{18}H_{11}N_5$ requires C, 72.72; H, 3.73; N, 23.56%); R_f 0.48 (DCM); λ_{max}(DCM)/nm 235 (log ε 3.62), 265 (3.36), 331 (4.24), 440 (4.31); ν_{max}/cm^{-1} 3237w (NH), 3063w and 3051w (Ar CH), 2234w and 2214w (C≡N), 1655w, 1609w, 1597w, 1578w, 1503m, 1493m, 1466s, 1441m, 1416s, 1331s, 1317m, 1275m, 1221m, 1196w, 1182w, 1163w, 1121m, 1072w, 1032w, 1000w, 980w, 941w, 872m, 843w, 781m; δ_H (500 MHz; $CDCl_3$) 10.39 (1H, s, N*H*), 9.26 (1H, s, N*H*), 7.71 (2H, d, *J* 7.5, Ar *H*), 7.67 (2H, d, *J* 7.5, Ar *H*), 7.64−7.62 (3H, m, Ar *H*), 7.60−7.56 (2H, m, Ar *H*), 7.54−7.52 (3H, m, Ar *H*), 7.38−7.34 (4H, m, Ar *H*), 7.25−7.23 (2H, m, Ar *H*), 7.20−7.18 (2H, m, Ar *H*); δ_H[500 MHz; $CDCl_3$/HCl (g)] NH resonance missing, 7.69 (2H, d, *J* 8.5, Ar *H*), 7.59−7.56 (4H, m, Ar *H*), 7.36 (2H, dd, *J* 8.0, 8.0, Ar *H*), 7.23−7.21 (2H, m, Ar *H*); δ_H (500 MHz; DMSO-d_6) 10.47 (1H, s, N*H*), 7.63−7.54 (6H, m, Ar *H*), 7.45−7.42 (4H, m, Ar *H*); δ_C (125 MHz; $CDCl_3$) 171.4 (s), 168.7 (s), 165.0 (s), 160.8 (s), 158.4 (s), 157.3 (s), 134.8 (d), 134.6 (d), 133.9 (s), 132.5 (s), 131.23 (d), 131.20 (d), 131.0 (d), 130.9 (d), 130.1 (d), 130.0 (d), 128.89 (d), 128.85 (d), 128.1 (d), 128.0 (d), 125.8 (s), 125.6 (s), 113.0 (s, *C*≡N), 112.5 (s, *C*≡N), 112.3 (s, *C*≡N), 111.7 (s, *C*≡N), 72.1 [s, *C*$(CN)_2$], 70.5 [s, *C*$(CN)_2$]; δ_C (125 MHz; DMSO-d_6) 170.0 (s), 167.0 (s), 155.6 (s), 134.1 (d), 132.5 (s), 130.4 (d), 130.3 (d), 130.2 (d), 128.72 (d), 128.69 (d), 126.1 (s), 113.6 (s, *C*≡N), 112.9 (s, *C*≡N), 67.1 [s, *C*$(CN)_2$]; *m*/*z* (MALDI-TOF) 299 (MH^+ + 1, 25%), 298 (MH^+, 100), 242 (2), 180 (4), 153 (70); *m*/*z* (EI) 297 (M^+, 58%), 296 (100), 271 (7), 244 (3), 194 (22), 180 (12), 167 (6), 153 (3), 118 (12), 104 (17), 91 (5), 77 (73), 65 (3), 51 (32).

*4.3.2. 2-[5-Imino-1-(4-methoxyphenyl)-2-phenyl-1H-imidazol-4(5H)-ylidene]malononitrile (**13b**).* Similar treatment of *N′*-(4-methoxyphenyl)-*N*-(1,2,2-tricyanovinyl)benzamidine (**12b**) (32.7 mg, 0.1 mmol) gave the title compound **13b** (29.1 mg, 89%) as orange prisms: mp (DSC) onset 187.1 °C, peak max. 191.1 °C, decomp. onset 195.4 °C, peak max. 203.0 °C (from cyclohexane/DCE, 50:50); (found C, 69.62; H, 3.90; N, 21.27. $C_{19}H_{13}N_5O$ requires C, 69.71; H, 4.00; N, 21.39%); R_f 0.38 (DCM); λ_{max}(DCM)/nm 233 (log ε 4.30), 267 (3.85), 276 inf (3.84), 283 inf (3.87), 319 (4.16), 378 inf (3.98), 447 (4.22); ν_{max}/cm^{-1} 3265w and 3232w (NH), 3069w (Ar CH), 2976 (CH_3), 2224w and 2208w (C≡N), 1653w, 1605w, 1595w,

dx.doi.org/10.1021/jo4013699 | J. Org. Chem. 2013, 78, 8655−8668

1578w, 1514m, 1504w, 1468s, 1445m, 1423m, 1410m, 1337m, 1304w, 1273m, 1256m, 1217m, 1182w, 1171w, 1123m, 1076w, 1020w, 1001w, 982w, 912w, 854w, 845m, 810w, 781w, 766w; δ_H[500 MHz; $CDCl_3$/HCl (g)] NH resonance missing, 7.73 (2H, dd, *J* 8.5, 1.0, Ar *H*), 7.58 (1H, dd, *J* 7.5, 7.5, Ar *H*), 7.37 (2H, dd, *J* 8.0, 8.0, Ar *H*), 7.13 (2H, d, *J* 9.0, Ar *H*), 7.05 (2H, d, *J* 9.0, Ar *H*), 3.89 (3H, s, OCH_3); δ_H (500 MHz; DMSO-d_6) 10.41 (1H, s, N*H*), 7.64−7.59 (3H, m, Ar *H*), 7.45 (2H, dd, *J* 8.0, 8.0, Ar *H*), 7.36 (2H, d, *J* 9.0, Ar *H*), 7.12 (2H, d, *J* 8.5, Ar *H*), 3.82 (3H, s, OCH_3); δ_C (125 MHz; DMSO-d_6) 170.2 (s), 167.1 (s), 160.2 (s), 156.3 (s), 134.1 (d), 130.5 (d), 130.2 (d), 128.8 (d), 126.3 (s), 124.8 (s), 115.6 (d), 113.7 (s, *C*≡N), 113.1 (s, *C*≡N), 66.4 [s, $C(CN)_2$], 55.5 (q, OCH_3); *m*/*z* (MALDI-TOF) 329 (MH^+ + 1, 24%), 328 (MH^+, 100), 252 (17), 210 (8), 153 (2).

*4.3.3. 2-[5-Imino-2-phenyl-1-p-tolyl-1H-imidazol-4(5H)-ylidene]-malononitrile (**13c**).* Similar treatment of *N*′-(*p*-tolyl)-*N*-(1,2,2-tricyanovinyl)benzamidine (**12c**) (31.1 mg, 0.1 mmol) gave the *title compound* ***13c*** (27.7 mg, 89%) as yellow needles: mp (DSC) onset 173.9 °C, peak max. 179.9 °C, decomp. onset 192.5 °C peak max. 202.7 °C (from *n*-pentane/THF, 90:10); (found C, 73.16; H, 4.15; N, 22.33. $C_{19}H_{13}N_5$ requires C, 73.30; H, 4.21; N, 22.49%); R_f 0.57 (DCM); λ_{max}(DCM)/nm 237 (log ε 4.07), 267 (3.89), 327 (4.22), 445 (4.29); ν_{max}/cm^{-1} 3227m (NH), 3065w and 3042w (Ar CH), 2230w and 2214w (C≡N), 1651w, 1607w, 1591w, 1578w, 1518m, 1503w, 1466s, 1439m, 1418s, 1331s, 1318w, 1300w, 1277m, 1221m, 1194w, 1182w, 1159w, 1121m, 1082w, 1070w, 1034w, 979w, 947w, 905w, 885m, 820m, 785m, 760w; δ_H[500 MHz; $CDCl_3$/HCl (g)] NH resonance missing, 7.72 (2H, d, *J* 7.5, Ar *H*), 7.58 (1H, dd, *J* 7.5, 7.5, Ar *H*), 7.38−7.35 (4H, m, Ar *H*), 7.09 (2H, d, *J* 8.0, Ar *H*), 2.46 (3H, s, CH_3); δ_H (500 MHz; DMSO-d_6) 10.41 (1*H*, s, N*H*), 7.62 (1*H*, dd, *J* 7.5, 7.5, Ar *H*), 7.58 (2H, d, *J* 8.0, Ar *H*), 7.44 (2H, dd, *J* 8.0, 7.5, Ar *H*), 7.39 (2H, d, *J* 8.0, Ar *H*), 7.30 (2H, d, *J* 8.0, Ar *H*), 2.40 (3H, s, CH_3); δ_C (125 MHz; DMSO-d_6) 170.1 (s), 167.0 (s), 155.9 (s), 139.9 (s), 134.1 (d), 130.9 (d), 130.4 (d), 129.8 (s), 128.7 (d), 128.5 (d), 126.2 (s), 113.7 (s, C≡N), 113.0 (s, C≡N), 66.7 [s, $C(CN)_2$], 20.8 (q, CH_3); *m*/*z* (MALDI-TOF) 313 (MH^+ + 1, 11%), 312 (MH^+, 100).

*4.3.4. 2-[1-(4-Fluorophenyl)-5-imino-2-phenyl-1H-imidazol-4(5H)-ylidene]malononitrile (**13d**).* Similar treatment of *N*′-(4-fluorophenyl)-*N*-(1,2,2-tricyanovinyl)benzamidine (**12d**) (31.5 mg, 0.1 mmol) gave the title compound **13d** (28.0 mg, 89%) as yellow needles: mp (DSC) onset 192.7 °C, peak max. 197.6 °C, decomp. onset 201.1 °C peak max. 210.1 °C (from *n*-pentane/THF, 90:10); (found C, 68.46; H, 3.33; N, 22.16. $C_{18}H_{10}FN_5$ requires C, 68.57; H, 3.20; N, 22.21%); R_f 0.50 (DCM); λ_{max}(DCM)/nm 238 (log ε 3.73), 265 (2.70), 331 (4.18), 440 (4.25); ν_{max}/cm^{-1} 3235m (NH), 3073w (Ar CH), 2232w and 2216w (C≡N), 1653w, 1609w, 1580w, 1512s, 1466s, 1445s, 1418s, 1331s, 1315w, 1300w, 1277m, 1236m, 1221s, 1194w, 1184w, 1167w, 1155w, 1121m, 1099w, 1080w, 1074w, 1032w, 1001w, 984m, 964w, 945w, 874m, 841m, 820w, 814w, 779m, 756w; δ_H[500 MHz; $CDCl_3$/HCl (g)] NH resonance missing, 7.69 (2H, d, *J* 8.0, Ar *H*), 7.60 (1H, dd, *J* 7.5, 7.5, Ar *H*), 7.39 (2H, dd, *J* 8.0, 8.0, Ar *H*), 7.27−7.21 (4H, m, Ar *H*); δ_H (500 MHz; DMSO-d_6) 11.02 (1H, s, N*H*), 8.05 (1H, dd, *J* 7.5, 7.5, Ar *H*), 7.98 (2H, d, *J* 8.0, Ar *H*), 7.94−97 (2H, m, Ar *H*), 7.89−7.84 (4H, m, Ar *H*); δ_C (125 MHz; DMSO-d_6) 170.0 (s), 167.0 (s), 162.6 (s, $^1J_{CF}$ 245.0, CF), 155.6 (s), 134.1 (d), 131.4 (d, $^3J_{CF}$ 8.8, CHCHCF), 130.4 (d), 128.84 (s), 128.77 (d), 126.1 (s), 117.3 (d, $^2J_{CF}$ 23.8, CHCF), 113.6 (s, C≡N), 112.9 (s, C≡N), 66.7 [s, $C(CN)_2$]; *m*/*z* (MALDI-TOF) 317 (MH^+ + 1, 13%), 316 (MH^+, 100), 252 (2), 198 (3), 105 (2).

*4.3.5. 2-[1-(4-Chlorophenyl)-5-imino-2-phenyl-1H-imidazol-4(5H)-ylidene]malononitrile (**13e**).* Similar treatment of *N*′-(4-chlorophenyl)-*N*-(1,2,2-tricyanovinyl)benzamidine (**12e**) (33.2 mg, 0.1 mmol) gave the title compound **13e** (28.9 mg, 87%) as yellow needles: mp (DSC) onset 188.6 °C, peak max. 193.5 °C, decomp. onset 198.2 °C peak max. 201.5 °C (from *n*-pentane/THF, 50:50); (found C, 65.16; H, 2.99; N, 20.94. $C_{18}H_{10}ClN_5$ requires C, 65.17; H, 3.04; N, 21.11%); R_f 0.55 (DCM); λ_{max}(DCM)/nm 230 (log ε 4.11), 267 (3.69), 332 (4.12), 440 (4.23); ν_{max}/cm^{-1} 3231m (NH), 3061w (Ar CH), 2230w and 2218w (C≡N), 1651w, 1609w, 1591w, 1578w, 1503m, 1495s, 1466s, 1443s, 1414s, 1329s, 1315w, 1302w, 1277m, 1223s, 1194w, 1182w, 1123m, 1094m, 1082w, 1074w, 1032w, 1020w, 980w, 947w, 878m, 835m, 822w, 781m, 754w; δ_H[500 MHz; $CDCl_3$/HCl (g)] NH resonance missing, 7.69 (2H, d, *J* 7.5, Ar *H*), 7.61 (1H, dd, *J* 7.5, 7.5, Ar *H*), 7.53 (2H, d, *J* 7.5, Ar *H*), 7.40 (2H, dd, *J* 8.0, 8.0, Ar *H*), 7.17 (2H, d, *J* 8.5, Ar *H*); δ_H (500 MHz; DMSO-d_6) 10.67 (1H, s, N*H*), 7.67−7.62 (3H, m, Ar *H*), 7.56 (2H, d, *J* 8.0, Ar *H*), 7.48−7.46 (4H, m, Ar *H*); δ_C (125 MHz; DMSO-d_6) 169.9 (s), 167.0 (s), 155.2 (s), 134.8 (s), 134.1 (d), 131.5 (s), 130.8 (d), 130.4 (d), 130.3 (d), 128.8 (d), 126.0 (s), 113.5 (s, *C*≡N), 112.9 (s, *C*≡N), 66.8 [s, $C(CN)_2$]; *m*/*z* (MALDI-TOF) 334 (MH^+ + 2, 25%), 333 (MH^+ + 1, 9), 332 (MH^+, 100), 214 (3), 153 (2).

*4.3.6. 2-[1-(3,4-Dichlorophenyl)-5-imino-2-phenyl-1H-imidazol-4(5H)-ylidene]malononitrile (**13f**).* Similar treatment of *N*′-(3,4-dichlorophenyl)-*N*-(1,2,2-tricyanovinyl)benzamidine (**12f**) (36.6 mg, 0.1 mmol) gave the title compound **13f** (31.7 mg, 87%) as orange needles: mp (DSC) onset 114.5 °C, peak max. 115.5 °C (from *n*-pentane/THF, 50:50); (found C, 50.51; H, 2.53; N, 15.51. $C_{18}H_9Cl_2N_5.CH_2Cl_2$ requires C, 50.58; H, 2.46; N, 15.52%); R_f 0.60 (DCM); λ_{max}(DCM)/nm 230 (log ε 4.11), 242 inf (4.00), 267 inf (3.68), 333 (4.12), 436 (4.24); ν_{max}/cm^{-1} 3316w (NH), 3096w and 3076w (Ar CH), 2224w (C≡N), 1647w, 1589w, 1578w, 1566w, 1497m, 1477s, 1464s, 1435s, 1414s, 1385m, 1335m, 1315w, 1298w, 1278m, 1271m, 1250w, 1234w, 1229w, 1219w, 1196w, 1182w, 1161w, 1134m, 1113w, 1101w, 1057m, 1036w, 1001w, 991w, 949w, 885w, 851m, 826m, 808w, 783m, 766m; δ_H[500 MHz; $CDCl_3$/HCl (g)] NH resonance missing, 7.71 (2H, d, *J* 7.0, Ar *H*), 7.64 (1H, dd, *J* 7.5, 7.5, Ar *H*), 7.60 (1H, br s, Ar *H*), 7.44 (2H, dd, *J* 8.0, 8.0, Ar *H*), 7.40 (1H, br s, Ar *H*), 7.06 (1H, dd, *J* 8.5, 2.0, Ar *H*); δ_H (500 MHz; DMSO-d_6) 10.87 (1H, s, N*H*), 7.87−7.85 (2H, m, Ar *H*), 7.65 (1H, dd, *J* 7.3, 7.3, Ar *H*), 7.59 (2H, d, *J* 7.5, Ar *H*), 7.49 (2H, dd, 7.8, 7.8, Ar *H*), 7.45 (1H, dd, *J* 8.5, 2.0, Ar *H*), 5.75 (2H, s, CH_2Cl_2); δ_C (125 MHz; DMSO-d_6) 169.7 (s), 166.8 (s), 154.7 (s), 134.2 (d), 133.1 (s), 132.6 (s), 132.5 (s), 132.1 (d), 131.2 (d), 130.3 (d), 129.5 (d), 128.9 (d), 125.9 (s), 113.4 (s, C≡N), 112.8 (s, *C*≡N), 67.0 [s, $C(CN)_2$], 54.8 (CH_2Cl_2); *m*/*z* (MALDI TOF) 370 (MH^+ + 4, 5%), 369 (MH^+ + 3, 11), 368 (MH^+ + 2, 52), 367 (MH^+ + 1, 16), 366 (MH^+, 100), 316 (16), 252 (4), 242 (7).

*4.3.7. 2-[1-(4-Bromophenyl)-5-imino-2-phenyl-1H-imidazol-4(5H)-ylidene]malononitrile (**13g**).* Similar treatment of *N*′-(4-bromophenyl)-*N*-(1,2,2-tricyanovinyl)benzamidine (**12g**) (37.6 mg, 0.1 mmol) gave the title compound **13g** (32.0 mg, 85%) as yellow needles: mp (DSC) onset 166.1 °C, peak max. 170.5 °C, decomp. onset 172.7 °C peak max. 173.0 °C (from *n*-pentane/THF, 90:10); (found C, 57.31; H, 2.64; N, 18.55. $C_{18}H_{10}BrN_5$ requires C, 57.47; H, 2.68; N, 18.62%); R_f 0.56 (DCM); λ_{max}(DCM)/nm 232 (log ε 4.27), 267 inf (3.81), 332 (4.17), 440 (4.28); ν_{max}/cm^{-1} 3233m (NH), 3063w (Ar CH), 2228w and 2218w (C≡N), 1649w, 1607w, 1591w, 1578w, 1493s, 1466s, 1439s, 1414s, 1404s, 1329s, 1314m, 1300m, 1277m, 1223m, 1192w, 1180m, 1121m, 1103w, 1080w, 1069w, 1032w, 1016w, 980w, 947w, 878m, 833m, 822w, 783m, 760w; δ_H[500 MHz; $CDCl_3$/HCl (g)] NH resonance missing, 7.69 (4H, d, *J* 7.5, Ar *H*), 7.61 (1H, dd, *J* 7.5, 7.5, Ar *H*), 7.41 (2H, dd, 8.0, 8.0, Ar *H*), 7.10 (2H, d, *J* 8.0, Ar *H*); δ_H (500 MHz; DMSO-d_6) 10.67 (1H, s, N*H*), 7.80 (2H, d, *J* 8.0, Ar *H*), 7.68 (1H, dd, *J* 7.0, 7.0, Ar *H*), 7.56 (2H, d, *J* 7.5, Ar *H*), 7.47 (2H, dd, *J* 7.5, 7.5, Ar *H*), 7.39 (2H, d, *J* 8.5, Ar *H*); δ_C (125 MHz; DMSO-d_6) 170.0 (s), 167.0 (s), 155.2 (s), 134.1 (d), 133.4 (d), 132.0 (s), 131.1 (d), 130.4 (d), 128.9 (d), 126.1 (s), 123.6 (s), 113.6 (s, C≡N), 113.0 (s, C≡N), 66.8 [s, $C(CN)_2$]; *m*/*z* (MALDI TOF) 379 (MH^+ + 3, 13%), 378 (MH^+ + 2, 90), 377 (MH^+ + 1, 8), 376 (MH^+, 100), 260 (12), 252 (18).

*4.3.8. 2-[1-(4-Iodophenyl)-5-imino-2-phenyl-1H-imidazol-4(5H)-ylidene]malononitrile (**13h**).* Similar treatment of *N*′-(4-iodophenyl)-*N*-(1,2,2-tricyanovinyl)benzamidine (**12h**) (42.3 mg, 0.1 mmol) gave the title compound **13h** (35.6 mg, 84%) as orange plates: mp (DSC) onset 172 °C, peak max. 176 °C, onset 185 °C decomp. 207 °C (from *n*-pentane/THF, 90:10); (found C, 50.92; H, 2.34; N, 16.49. $C_{18}H_{10}IN_5$ requires C, 51.08; H, 2.38; N, 16.55%); R_f 0.59 (DCM); λ_{max}(DCM)/nm 243 (log ε 4.65), 324 (4.43), 441 (4.54); ν_{max}/cm^{-1} 3316w (NH), 3084w and 3032w (Ar CH), 2222w (C≡N), 1641w, 1607w, 1589w, 1576w, 1501m, 1491m, 1468s, 1441s, 1416s, 1398m, 1335m, 1312w, 1298w, 1267m, 1244w, 1225w, 1196w, 1180w, 1161w,

dx.doi.org/10.1021/jo4013699 | J. Org. Chem. 2013, 78, 8655−8668

1130m, 1103w, 1067m, 1055w, 1028w, 1011w, 1001w, 989w, 979w, 941w, 831m, 824m, 783w, 764m; δ_H[500 MHz; $CDCl_3$/HCl (g)] NH resonance missing, 7.88 (2H, d, *J* 8.5, Ar *H*), 7.70 (2H, d, *J* 7.5, Ar *H*), 7.61 (1H, dd, *J* 7.5, 7.5, Ar *H*), 7.41 (2H, dd, *J* 8.0, 8.0, Ar *H*), 6.96 (2H, d, *J* 8.5, Ar *H*); δ_H (500 MHz; DMSO-d_6) 10.66 (1H, s, N*H*), 7.95 (2H, d, *J* 8.5, Ar *H*), 7.63 (1H, dd, *J* 7.5, 7.5, Ar *H*), 7.56 (2H, d, *J* 7.5, Ar *H*), 7.47 (2H, dd, *J* 7.8, 7.8, Ar *H*), 7.22 (2H, d, *J* 8.5, Ar *H*); δ_C (125 MHz; DMSO-d_6) 169.9 (s), 167.0 (s), 155.1 (s), 139.2 (d), 134.1 (d), 131.9 (s), 130.9 (d), 130.3 (d), 128.8 (d), 126.1 (s), 113.6 (s, C≡N), 112.9 (s, C≡N), 97.2 (s), 66.8 [s, $C(CN)_2$]; *m*/*z* (MALDI TOF) 425 (MH^+ + 1, 15%), 424 (MH^+, 100), 153 (4).

*4.3.9. 2-[5-Imino-1-(4-nitrophenyl)-2-phenyl-1H-imidazol-4(5H)-ylidene]malononitrile (**13i**).* Similar treatment of *N*′-(4-nitrophenyl)-*N*-(1,2,2-tricyanovinyl)benzamidine (**12i**) (34.2 mg, 0.1 mmol) gave the title compound **13i** (31.5 mg, 92%) as yellow plates: mp (DSC) onset 209 °C, peak max. 214 °C, decomp. onset 219.4 °C, peak max. 224.2 °C (from *n*-pentane/DCE, 90:10); (found C, 63.03; H, 2.99; N, 24.51. $C_{18}H_{10}N_6O_2$ requires C, 63.16; H, 2.94; N, 24.55%); R_f 0.35 (DCM); λ_{max}(DCM)/nm 229 (log ε 4.12), 264 (4.09), 325 (4.23), 433 (4.25); ν_{max}/cm^{-1} 3285w (NH), 3115w and 3084w (Ar CH), 2224w and 2216w (C≡N), 1663w, 1611w, 1591w, 1574w, 1520m, 1497m, 1468s, 1439m, 1416w, 1391m, 1348s, 1331w, 1315w, 1298w, 1275w, 1209m, 1186w, 1177w, 1113w, 1103w, 1061m, 1024w, 1013w, 1001w, 980w, 934w, 864m, 853m, 835m, 789m, 773w; δ_H[500 MHz; $CDCl_3$/HCl (g)] 8.43−8.37 (2H, m, Ar *H*), 7.69−7.61 (3H, m, Ar *H*), 7.46−7.43 (4H, m, Ar *H*); δ_H (500 MHz; DMSO-d_6) 10.80 (1H, s, N*H*), 8.43 (2H, d, *J* 8.0, Ar *H*), 7.70 (2H, d, *J* 8.5 Ar *H*), 7.64 (1H, dd, *J* 6.8, 6.8, Ar *H*), 7.55 (2H, d, *J* 6.5, Ar *H*), 7.46 (2H, dd, *J* 7.3, 7.3, Ar *H*); δ_C (125 MHz; DMSO-d_6) 169.8 (s), 166.9 (s), 154.4 (s), 147.9 (s), 138.4 (s), 134.1 (d), 130.44 (d), 130.38 (d), 129.1 (d), 128.9 (d), 125.8 (s), 125.5 (d), 113.4 (s, C≡N), 112.8 (s, C≡N), 66.9 [s, $C(CN)_2$]; *m*/*z* (MALDI TOF) 344 (MH^+ + 1, 27%), 343 (MH^+, 100), 252 (90), 225 (18), 153 (8), 105 (53).

4.4. Conversion of *N*-Aryl-*N*-(1,2,2-tricyanovinyl)-benzamidines into (*Z*)-2-[2-Phenyl-4-(arylimino)-1*H*-imidazol-5(4*H*)-ylidene]malononitriles. *4.4.1. (Z)-2-[2-Phenyl-4-(phenylimino)-1H-imidazol-5(4H)-ylidene]malononitrile (**14a**).* A solution of *N*′-phenyl-*N*-(1,2,2-tricyanovinyl)benzamidine (**12a**) (29.7 mg, 0.1 mmol) in MeOH (1 mL) left to stir at ca. 67 °C for 1 h and chromatography of the residue (DCM/Et_2O, 95:05) gave the title compound **14a** (27.5 mg, 92%), as orange fibers: mp (DSC) decomp. onset 254.9 °C, peak max. 256.7 °C (from cyclohexane/DCE, 50:50); (found C, 72.82; H, 3.54; N, 23.43. $C_{18}H_{11}N_5$ requires C, 72.72; H, 3.73; N, 23.56%); R_f 0.71 (DCM/Et_2O, 95:05); λ_{max}(pyridine)/nm 345 (4.28), 365 inf (4.16), 390 inf (3.96), 414 inf (3.88), 505 inf (4.05), 542 (4.28), 582 (4.30) λ_{max}(DCM)/nm 229 (log ε 4.10), 259 inf (4.01), 267 inf (4.04), 286 inf (4.12), 323 (4.26), 424 (4.28), 452 (4.26), 483 inf (4.17), 556 inf (3.17), 598 inf (3.03); λ_{max}(acetone)/nm 333 (log ε 4.27), 426 inf (4.20), 456 (4.24), 484 inf (4.18), 539 inf (3.67), 580 (3.58); λ_{max}(DMF)/nm 271 inf (log ε 4.30), 282 (4.33), 292 inf (4.32), 308 inf (4.24), 331 (4.28), 344 (4.31), 365 inf (4.21), 387 inf (4.00), 414 inf (3.86), 501 inf (4.06), 539 (4.33), 579 (4.37); λ_{max}(DMSO)/nm 272 inf (log ε 4.29), 283 (4.31), 293 inf (4.30), 308 inf (4.23), 332 inf (4.28), 346 (4.31), 365 inf (4.02), 389 inf (4.02), 415 inf (3.91), 503 inf (4.08), 538 (4.33), 578 (4.34); ν_{max}/cm^{-1} 3196w (NH), 3047w (Ar CH), 2230m and 2220w (C≡N), 1641m, 1601m, 1582m, 1570m, 1530s, 1491w, 1458m, 1418w, 1335w, 1319m, 1308m, 1294m, 1285s, 1225m, 1204m, 1180m, 1171m, 1155w, 1078w, 1065m, 1024w, 999w, 966m, 932w, 922m, 849m, 785m, 773s; δ_H (500 MHz; DMSO-d_6) 12.62 (1H, s, N*H*), 8.32 (2H, d, *J* 7.5, Ar *H*), 7.77 (1H, dd, *J* 7.5, 7.5, Ar *H*), 7.63 (2H, dd, *J* 7.8, 7.8, Ar *H*), 7.49 (2H, dd, *J* 7.5, 7.5, Ar *H*), 7.45 (2H, br s, Ar *H*), 7.31 (1H, d, *J* 7.3, Ar *H*); δ_C (125 MHz; DMSO-d_6) five carbon resonances missing possibly because of prototautomerism 146.7 (s), 135.5 (d), 130.5 (d), 129.7 (d), 129.6 (d), 126.6 (s), 114.6 (s, C≡N), 114.1 (s, C≡N); *m*/*z* (EI) 297 (M^+, 100%), 296 (62), 271 (22), 194 (48), 180 (5), 167 (12), 135 (5), 118 (25), 104 (71), 103 (67), 91 (7), 77 (78), 63 (6), 51 (26); *m*/*z* (MALDI-TOF) 299 (MH^+ + 1, 17%), 298 (MH^+, 100%), 153 (1).

*4.4.2. (Z)-2-{4-[(4-Methoxyphenyl)imino]-2-phenyl-1H-imidazol-5(4H)ylidene}malononitrile (**14b**).* Similar treatment of *N*′-(4-methoxyphenyl)-*N*-(1,2,2-tricyanovinyl)benzamidine (**12b**) (32.7 mg, 0.1 mmol) gave the title compound **14b** (30.0 mg, 91%), as red fibers: mp (DSC) decomp. onset 258.5 °C, peak max. 260.3 °C (from cyclohexane/DCE, 50:50); (found C, 69.72; H, 3.95; N, 21.30. $C_{19}H_{13}N_5O$ requires C, 69.71; H, 4.00; N, 21.39%); R_f 0.63 (DCM/Et_2O, 95:05); λ_{max}(DMF)/nm 281 inf (log ε 4.28), 290 (4.27), 300 (4.27), 341 inf (4.15), 403 (4.06), 427 (4.04), 481 inf (3.92), 503 inf (4.11), 540 (4.34), 583 (4.39); ν_{max}/cm^{-1} 3202w (NH), 2843w (CH_3), 2224m and 2212w (C≡N), 1641m, 1611w, 1599m, 1582m,1566s, 1520s, 1491m, 1454m, 1443w, 1427w, 1333w, 1312m, 1300m, 1290m, 1254s, 1242m, 1196w, 1182w, 1167m, 1159s, 1148s, 1061w, 1024s, 970w, 922s, 843s, 806w, 785m, 764w; δ_H (500 MHz; DMSO-d_6) 13.04 (1H, br s, N*H*), 8.32 (2H, d, *J* 7.5, Ar *H*), 7.76−7.73 (3H, m, Ar *H*), 7.62 (2H, dd, *J* 7.5, 7.5, Ar *H*), 7.06 (2H, d, *J* 8.5, Ar *H*), 3.83 (3H, s, OCH_3); δ_C (125 MHz; DMSO-d_6) five carbon resonances missing possibly because of prototautomerism 159.7 (s), 139.1 (s), 134.4 (d), 129.5 (d), 129.0 (d), 126.2 (s), 114.6 (d), 114.2 (s, C≡N), 113.8 (s, C≡N), 55.4 (q, OCH_3); *m*/*z* (MALDI-TOF) 329 (MH^+ + 1, 23%), 328 (MH^+, 100), 327 (M^+, 16).

*4.4.3. (Z)-2-[2-Phenyl-4-(p-tolylimino)-1H-imidazol-5(4H)-ylidene]malononitrile (**14c**).* Similar treatment of *N*′-(*p*-tolyl)-*N*-(1,2,2-tricyanovinyl)benzamidine (**12c**) (31.1 mg, 0.1 mmol) gave the title compound **14c** (29.1 mg, 94%), as orange fibers: mp (DSC) decomp. onset 271.4 °C, peak max. 272.0 °C (from cyclohexane/DCE, 50:50); (found C, 73.28; H, 4.17; N, 22.58. $C_{19}H_{13}N_5$ requires C, 73.30; H, 4.21; N, 22.49%); R_f 0.76 (DCM/Et_2O, 95:05); λ_{max}(DMF)/nm 275 inf (log ε 4.45), 286 (4.47), 295 inf (4.47), 311 inf (4.42), 338 (4.420), 369 inf (4.28), 394 (4.20), 420 (4.18), 469 inf (4.12), 504 (4.31), 538 (4.44), 581 (4.47); ν_{max}/cm^{-1} 3211w (NH), 3055w and 3030w (Ar CH), 2226m and 2216w (C≡N), 1643s, 1612m, 1601m, 1584s, 1572s, 1526s, 1489m, 1456s, 1416w, 1331w, 1312s, 1296s, 1284s, 1231m, 1194m, 1173s, 1101w, 1076w, 1061w, 1032w, 1014w, 1001w, 970w, 955w, 922m, 856w, 827s, 806w, 785s, 766w; δ_H (500 MHz; DMSO-d_6) 12.88 (1H, s, N*H*), 8.32 (2H, d, *J* 7.0, Ar *H*), 7.77 (1H, d, *J* 7.5, 7.5, Ar *H*), 7.63 (2H, dd, *J* 7.8, 7.8, Ar *H*), 7.45 (2H, br s, Ar *H*), 7.30 (2H, d, *J* 8.5, Ar *H*), 2.37 (3H, s, CH_3); δ_C (125 MHz; DMSO-d_6) six carbon resonances missing possibly because of prototautomerism 143.5 (s), 134.8 (d), 129.8 (d), 129.7 (d), 129.0 (d), 126.0 (s), 114.1 (s, C≡N), 113.5 (s, C≡N), 20.8 (q, CH_3); *m*/*z* (MALDI-TOF) 313 (MH^+ + 1, 25%), 312 (MH^+, 100), 153 (2).

*4.4.4. (Z)-2-{4-[(4-Fluorophenyl)imino]-2-phenyl-1H-imidazol-5(4H)-ylidene}malononitrile (**14d**).* Similar treatment of *N*′-(4-fluorophenyl)-*N*-(1,2,2-tricyanovinyl)benzamidine (**12d**) (31.5 mg, 0.1 mmol) gave the title compound **14d** (27.8 mg, 88%), as orange fibers: mp (DSC) onset 267.4 °C, peak max. 267.7 °C, decomp. onset 268.7 °C, peak max. 271.2 °C (from cyclohexane/DCE, 50:50); (found C, 68.56; H, 3.27; N, 22.15. $C_{18}H_{10}FN_5$ requires C, 68.57; H, 3.20; N, 22.21%); R_f 0.65 (DCM/Et_2O, 95:05); λ_{max}(DMF)/nm 275 inf (log ε 4.44), 282 (4.46), 292 inf (4.44), 307 inf (4.37), 339 (4.40), 363 inf (4.33), 387 inf (4.18), 412 inf (4.09), 465 inf (3.96), 501 inf (4.19), 537 (4.41), 578 (4.47); ν_{max}/cm^{-1} 3229w (NH), 3053w (Ar CH), 2226m and 2210w (C≡N), 1647m, 1601m, 1570s, 1530s, 1487m, 1456m, 1414w, 1335w, 1314m, 1298m, 1287s, 1233s, 1213m, 1194m, 1167w, 1159m, 1146m, 1096w, 1061m, 1028w, 1010w, 1001w, 982w, 968w, 951m, 933w, 920m, 903w, 860w, 843s, 814m, 785m, 777m; δ_H (500 MHz; DMSO-d_6) 12.87 (1H, br s, N*H*), 8.32 (2H, d, *J* 7.5, Ar *H*), 7.78 (1H, dd, *J* 7.3, 7.3, Ar *H*), 7.64 (3H, dd, *J* 7.5, 7.5, Ar *H*), 7.52 (1H, br s, Ar *H*), 7.32 (2H, dd, *J* 8.5, 8.5, Ar *H*); δ_C (125 MHz; DMSO-d_6) five carbon resonances missing possibly because of prototautomerism 163.3 (d, $^1J_{CF}$ 84.6, CF), 161.0 (d, $^2J_{CF}$ 246.3, CF), 142.5 (s), 134.9 (d), 129.8 (d), 129.0 (d), 125.9 (s), 116.0 (d, $^3J_{CF}$ 22.5, CHCF), 113.9 (s, C≡N), 113.4 (s, C≡N); *m*/*z* (MALDI-TOF) 317 (MH^+ + 1, 27%), 316 (MH^+, 100), 153 (3).

*4.4.5. (Z)-2-{4-[(4-Chlorophenyl)imino]-2-phenyl-1H-imidazol-5(4H)-ylidene}malononitrile (**14e**).* Similar treatment of *N*′-(4-chlorophenyl)-*N*-(1,2,2-tricyanovinyl)benzamidine (**12e**) (33.2 mg, 0.1 mmol) gave the title compound **14e** (28.6 mg, 86%), as orange

dx.doi.org/10.1021/jo4013699 | J. Org. Chem. 2013, 78, 8655−8668

fibers: mp (DSC) onset 269.0 °C, peak max 269.5 °C, decomp. onset 270.1 °C, peak max. 271.9 °C (from cyclohexane/DCE, 50:50); (found C, 65.24; H, 3.15; N, 21.01. $C_{18}H_{10}ClN_5$ requires C, 65.17; H, 3.04; N, 21.11%); R_f 0.71 (DCM/Et_2O, 95:05); λ_{max}(DMF)/nm 277 inf (log ε 4.43), 286 inf (4.46), 296 (4.46), 310 inf (4.42), 339 (4.42), 366 inf (4.32), 393 (4.18), 418 (4.12), 471 inf (4.01), 507 inf (4.23), 544 (4.43), 585 (4.46); ν_{max}/cm^{-1} 3208w (NH), 3048w (Ar CH), 2228m and 2218w (C≡N), 1641m, 1607m, 1595m, 1582m, 1568s, 1526s, 1493w, 1477m, 1456m, 1416w, 1312s, 1300s, 1290s, 1275w, 1236m, 1205w, 1190m, 1169m, 1092s, 1061w, 1030w, 1009m, 1001w, 972m, 955w, 922m, 839s, 802w, 785s, 756w; δ_H (500 MHz; DMSO-d_6) 12.69 (1H, br s, N*H*), 8.32 (2H, d, *J* 7.5, Ar *H*), 7.79 (1H, dd, *J* 7.3, 7.3, Ar *H*), 7.65 (2H, dd, *J* 7.8, 7.8, Ar *H*), 7.55 (2H, d, *J* 8.0, Ar *H*), 7.46 (2H, br s, Ar *H*); δ_C (125 MHz; DMSO-d_6) six carbon resonances missing possibly because of prototautomerism 145.1 (s), 135.0 (d), 129.9 (d), 129.1 (d), 129.01 (d), 126.5 (s), 114.0 (s, *C*≡N), 113.4 (s, *C*≡N); *m*/*z* (MALDI-TOF) 335 (MH^+ + 3, 7%), 334 (MH^+ + 2, 39), 333 (MH^+ + 1, 20), 332 (MH^+, 100).

4.4.6. (Z)-2-{4-[(3,4-Dichlorophenyl)imino]-2-phenyl-1H-imidazol-5(4H)-ylidene}malononitrile (14f). Similar treatment of *N*′-(3,4-dichlorophenyl)-*N*-(1,2,2-tricyanovinyl)benzamidine (**12f**) (36.6 mg, 0.1 mmol) gave the title compound **14f** (32.9 mg, 90%), as red fibers: mp (DSC) onset 267.2 °C, peak max 269.1 °C, decomp. onset 270.5 °C, peak max. 274.8 °C (from cyclohexane/DCE, 50:50); (found C, 59.19; H, 2.50; N, 19.20. $C_{18}H_9Cl_2N_5$ requires C, 59.04; H, 2.48; N, 19.12%); R_f 0.67 (DCM/Et_2O, 95:05); λ_{max}(DMF)/nm 285 inf (log ε 4.38), 296 (4.39), 310 (4.34), 348 (4.32), 369 inf (4.25), 393 (4.11), 419 inf (3.99), 476 inf (3.82), 510 inf (4.37), 548 (4.37), 591 (4.41); ν_{max}/cm^{-1} 3198w (NH), 3049w (Ar CH), 2234m and 2218w (C≡N), 1647m, 1605m, 1564s, 1528s, 1493m, 1454s, 1416w, 1383w, 1333w, 1312s, 1296s, 1271w, 1254w, 1219s, 1192m, 1161w, 1124m, 1063w, 1024s, 1001w, 970m, 924s, 901m, 891s, 829m, 816w, 779m; δ_H (500 MHz; DMSO-d_6) 12.72 (1H, br s, N*H*), 8.29 (3H, d, *J* 7.5, Ar *H*), 7.79 (1H, dd, *J* 7.5, 7.5, Ar *H*), 7.72 (1H, d, Ar *H*), 7.65 (2H, dd, *J* 7.5, 7.5, Ar *H*), 7.34 (2H, br s, Ar *H*); δ_C (125 MHz; DMSO-d_6) seven peaks missing possibly because of prototautomerism 171.7 (s), 146.4 (s), 135.2 (d), 131.5 (s), 131.0 (d), 129.9 (d), 129.1 (d), 126.0 (s), 113.8 (s, C≡N), 113.2 (s, *C*≡N); *m*/*z* (MALDI-TOF) 370 (MH^+ + 4, 1%), 369 (MH^+ + 3, 1), 368 (MH^+ + 2, 12), 367 (MH^+ + 1, 3), 366 (MH^+, 23), 271 (2), 153 (100).

4.4.7. (Z)-2-{4-[(4-Bromophenyl)imino]-2-phenyl-1H-imidazol-5(4H)-ylidene}malononitrile (14g). Similar treatment of *N*′-(4-bromophenyl)-*N*-(1,2,2-tricyanovinyl)benzamidine (**12g**) (37.6 mg, 0.1 mmol) gave the title compound **14g** (32.8 mg, 87%), as orange fibers: mp (DSC) onset 278.1 °C, peak max 278.4 °C, decomp. onset 279.0 °C, peak max. 281.7 °C (from cyclohexane/DCE, 50:50); (found C, 57.40; H, 2.73; N, 18.75. $C_{18}H_{10}BrN_5$ requires C, 57.47; H, 2.68; N, 18.62%); R_f 0.72 (DCM/Et_2O, 95:05); λ_{max}(DMF)/nm 287 inf (log ε 4.39), 296 (4.40), 310 (4.35), 347 (4.34), 366 inf (4.26), 394 inf (4.10), 417 inf (3.98), 476 inf (3.80), 508 inf (4.15), 545 (4.41), 586 (4.44); ν_{max}/cm^{-1} 3208w (NH), 3044w (Ar CH), 2228m and 2218w (C≡N), 1643m, 1605m, 1593m, 1581w, 1566s, 1526s, 1493w, 1474m, 1456m, 1416w, 1312s, 1300s, 1290s, 1271w, 1234m, 1200w, 1169s, 1028w, 1007m, 970w, 922m, 835s, 785s, 756w; δ_H (500 MHz; DMSO-d_6) 12.68 (1H, br s, N*H*), 8.31 (2H, d, *J* 7.5 Ar *H*), 7.78 (1H, dd, *J* 7.5, 7.5, Ar *H*), 7.68−7.63 (4H, m, Ar *H*), 7.35 (2H, br s, Ar *H*); δ_C (125 MHz; DMSO-d_6) six carbon resonances missing possibly because of prototautomerism 145.5 (s), 135.1 (d), 132.1 (d), 129.9 (d), 129.1 (d), 126.0 (s), 113.9 (s, *C*≡N), 113.4 (s, *C*≡N); *m*/*z* (MALDI-TOF) 379 (MH^+ + 3, 9%), 378 (MH^+ + 2, 58), 377 (MH^+ + 1, 10), 376 (MH^+, 100), 260 (47), 258 (90), 153 (30), 105 (17).

4.4.8. (Z)-2-{4-[(4-Iodophenyl)imino]-2-phenyl-1H-imidazol-5(4H)-ylidene}malononitrile (14h). Similar treatment of *N*′-(4-iodophenyl)-*N*-(1,2,2-tricyanovinyl)benzamidine (**12h**) (37.6 mg, 0.1 mmol) gave the title compound **14h** (35.9 mg, 85%), as orange fibers: mp (DSC) onset 281.4 °C, peak max 282.5 °C, decomp. onset 283.2 °C, peak max. 284.8 °C (from cyclohexane/DCE, 50:50); (found C, 51.17; H, 2.46; N, 16.46. $C_{18}H_{10}IN_5$ requires C, 51.08; H, 2.38; N, 16.55%); R_f 0.74 (DCM/Et_2O, 95:05); λ_{max}(DMF)/nm 290 (log ε 4.39), 312 (3.35), 344 (4.33), 395 inf (4.07), 421 inf (3.95), 482 inf (3.80), 509 inf (4.12), 546 (4.39), 587 (4.42); ν_{max}/cm^{-1} 3202w (NH), 3046w (Ar CH), 2230m and 2220w (C≡N), 1643m, 1607m, 1593m, 1582w, 1562s, 1526s, 1493m, 1474m, 1455s, 1416w, 1335w, 1312s, 1300s, 1290s, 1269w, 1234m, 1221w, 1200m, 1171m, 1055m, 1028w, 1003s, 970m, 920m, 849w, 831s, 800w, 787s; δ_H (500 MHz; DMSO-d_6) 12.59 (1H, br s, N*H*), 8.31 (2H, d, *J* 7.5, Ar *H*), 7.83 (2H, d, *J* 8.5, Ar *H*), 7.78 (2H, dd, *J* 7.5, 7.5, Ar *H*), 7.64 (2H, dd, *J* 7.8, 7.8, Ar *H*), 7.20 (2H, br s, Ar *H*); δ_C (125 MHz; DMSO-d_6) six carbon resonances missing possibly because of prototautomerism 145.9 (s), 137.9 (d), 135.1 (d), 129.9 (d), 129.1 (d), 125.9 (s), 113.9 (s, *C*≡N), 113.4 (s, *C*≡N), *m*/*z* (MALDI-TOF) 426 (MH^+ + 2, 3%), 425 (MH^+ + 1, 18), 424 (MH^+, 100), 252 (3).

4.4.9. (Z)-2-{4-[(4-Nitrophenyl)imino]-2-phenyl-1H-imidazol-5(4H)-ylidene}malononitrile (14i). Similar treatment of *N*′-(4-nitrophenyl)-*N*-(1,2,2-tricyanovinyl)benzamidine (**12i**) (34.2 mg, 0.1 mmol) gave the title compound **14i** (31.9 mg, 93%), as red fibers: mp (DSC) onset 299.3 °C, peak max 299.9 °C, decomp. onset 300.5 °C, peak max. 303.4 °C (from *n*-pentane/DCE, 50:50); (found C, 63.26; H, 3.04; N, 24.54. $C_{18}H_{10}N_6O_2$ requires C, 63.16; H, 2.94; N, 24.55%); R_f 0.40 (DCM/Et_2O, 95:05); λ_{max}(DMF)/nm 353 (log ε 4.92), 524 inf (4.27), 567 (4.50), 612 (4.44); ν_{max}/cm^{-1} 3244w (NH), 3103w (Ar CH), 2232w and 2222w (C≡N), 1649w, 1609w, 1599w, 1589w, 1535s, 1514m, 1493w, 1481w, 1456m, 1414w, 1344s, 1333m, 1319m, 1298m, 1288s, 1236w, 1202w, 1188w, 1157w, 1107w, 1061w, 1026w, 1001w, 972w, 922w, 862s, 835w, 800w, 785w, 762w; δ_H (500 MHz; DMSO-d_6) 12.56 (1H, br s, N*H*), 8.33 (2H, d, *J* 8.5, Ar *H*), 8.29 (2H, d, *J* 7.5, Ar *H*), 7.79 (1H, dd, *J* 7.0, 7.0, Ar H), 7.64 (2H, dd, *J* 7.0, 7.0, Ar H), 7.47 (2H, br s, Ar *H*); δ_C (125 MHz; DMSO-d_6) five carbon resonances missing possibly because of prototautomerism 152.8 (s), 144.7 (s), 135.4 (d), 130.0 (d), 129.2 (d), 125.9 (s), 124.9 (d), 113.7 (s, *C*≡N), 113.2 (s, *C*≡N), 67.0 [s, *C*(CN)$_2$]; *m*/*z* (MALDI-TOF) 344 (MH^+ + 1, 16%), 343 (MH^+, 52), 226 (6), 172 (6), 153 (100), 116 (5).

4.5. Methylation of (*Z*)-2-[2-Phenyl-4-(phenylimino)-1*H*-imidazol-5(4*H*)-ylidene]malononitrile (14a). To a stirred solution of (*Z*)-2-[2-phenyl-4-(phenylimino)-1*H*-imidazol-5(4*H*)-ylidene]-malononitrile (**14a**) (29.7 mg, 0.1 mmol) in dry THF (1 mL) at ca. 20 °C was added NaH (4.8 mg, 0.2 mmol) and dimethyl sulfate (19 μL, 0.2 mmol). The mixture was heated at ca. 66 °C for 3 h and then allowed to cool to ca. 20 °C. Removal of the volatiles followed by chromatography (DCM/*n*-hexane, 70:30) of the residue gave (*Z*)-2-[1-methyl-2-phenyl-4-(phenylimino)-1*H*-imidazol-5(4*H*)-ylidene]-malononitrile (**16**) (27.3 mg, 88%) as orange needles: mp (DSC) onset 216.1 °C, peak max. 216.8 °C, decomp. onset 241.8 °C, peak max. 259.1 °C (from cyclohexane/DCE, 80:20); (found C, 73.17; H, 4.22; N, 22.36. $C_{19}H_{13}N_5$ requires C, 73.30; H, 4.21; N, 22.49%); R_f 0.47 (DCM/*n*-hexane, 70:30); λ_{max}(pyridine)/nm 325 (log ε 4.10), 404 inf (3.90), 431 inf (4.06), 461 (4.20), 488 (4.21); λ_{max}(DCM)/nm 281 (log ε 4.18), 319 (4.11), 401 inf (3.99), 427 (4.14), 457 (4.27), 483 (4.28); λ_{max}(acetone)/nm 332 (log ε 4.06), 401 inf (3.96), 427 inf (4.14), 454 (4.27), 480 (4.21); λ_{max}(DMF)/nm 277 (log ε 4.14), 322 (4.12), 404 inf (3.95), 431 inf (4.13), 460 (4.27), 485 (4.26); λ_{max}(DMSO)/nm 278 (log ε 4.13), 327 (4.11), 405 inf (3.92), 433 inf (4.09), 463 (4.22), 490 (4.22), 580 (2.94);; ; ν_{max}/cm^{-1} 3074w (Ar CH), 2949w (CH_3), 2218w (C≡N), 1636w, 1595m, 1580w, 1570m, 1524s, 1489m, 1460w, 1445m, 1437w, 1369w, 1325s, 1306s, 1290m, 1232m, 1198w, 1182m, 1161w, 1074w, 1061s, 1041w, 1024w, 1001w, 966w, 932w, 924w, 866w, 847m, 841m, 812w, 779s, 771s; δ_H (500 MHz; DMSO-d_6) 7.86 (2H, d, *J* 7.5, Ar *H*), 7.75−7.70 (3H, m, Ar *H*), 7.65 (2H, dd, *J* 7.8, 7.8, Ar *H*), 7.48 (2H, dd, *J* 7.8, 7.8, Ar *H*), 7.34 (1H, dd, *J* 7.3, 7.3, Ar *H*), 3.65 (3H, s, CH_3); δ_C (125 MHz; DMSO-d_6) 171.4 (s), 158.5 (s), 156.6 (s), 145.5 (s), 132.9 (d), 129.7 (d), 129.0 (d), 128.9 (d), 128.5 (d), 126.2 (d), 126.1 (s), 113.9 (s, C≡N), 113.5 (s, *C*≡N), 58.1 [s, *C*(CN)$_2$], 34.5 (q, CH_3); *m*/*z* (MALDI-TOF) 312 (MH^+, 7%), 153 (100). Further elution (DCM) gave (*Z*)-2-[1-methyl-2-phenyl-5-(phenylimino)-1*H*-imidazol-4(5*H*)-ylidene]-malononitrile (**17**) (0.8 mg, 2%) as orange plates: mp (DSC) decomp. onset 213.2 °C, peak max. 215.4 °C (from *n*-pentane/DCM, 80:20); (found C, 73.13; H, 4.16; N, 22.21. $C_{19}H_{13}N_5$ requires C, 73.30; H, 4.21; N, 22.49%); R_f 0.52 (DCM); λ_{max}(pyridine)/nm 332 (log ε

dx.doi.org/10.1021/jo4013699 | J. Org. Chem. 2013, 78, 8655−8668

4.12), 445 (4.10), 488 inf (4.06), 527 inf (3.83); λ_{max}(DCM)/nm 230 (log ε 4.23), 267 (4.05), 322 (4.26), 336 inf (4.16), 436 (4.19), 496 inf (4.01); λ_{max}(acetone)/nm 333 (log ε 4.13), 447 (4.18), 482 inf (4.11); λ_{max}(DMF)/nm 267 (log ε 4.22), 324 (4.24), 340 inf (4.14), 449 (4.12), 486 inf (4.06); λ_{max}(DMSO)/nm 268 (log ε 4.16), 327 (4.24), 451 (4.00), 500 inf (3.99), 535 inf (3.89), 580 (3.68); ν_{max}/cm^{-1} 3082w and 3061w (Ar CH), 2830w (CH_3), 2218w (C≡N), 1659w, 1649w, 1607w, 1589w, 1576w, 1506m, 1470s, 1437s, 1387s, 1339m, 1296w, 1229m, 1196w, 1180w, 1097w, 1070w, 1051m, 1022w, 999w, 937w, 922m, 843m, 804w, 783w, 756m; δ_H (500 MHz; $CDCl_3$) 7.89 (2H, d, *J* 7.7, Ar *H*), 7.68 (1H, dd, *J* 7.5, 7.5, Ar *H*), 7.57 (2H, dd, *J* 7.8, 7.8, Ar *H*), 7.41 (2H, dd, *J* 8.0, 8.0, Ar *H*), 7.21 (1H, dd, *J* 7.3, 7.3, Ar *H*), 7.06 (1H, d, *J* 7.8, Ar *H*), 3.03 (3H, s, CH_3); δ_C (125 MHz; $CDCl_3$) one quaternary C (s) resonance missing 174.5 (s), 147.5 (s), 145.2 (s), 134.2 (d), 130.2 (d), 129.3 (d), 129.1 (d), 126.4 (s), 126.0 (d), 120.7 (d), 113.0 (s, C≡N), 112.5 (s, C≡N), 71.8 [s, $C(CN)_2$], 35.9 (q, CH_3); *m*/*z* (MALDI-TOF) 312 (MH^+, 22%), 290 (12), 289 (100), 205 (19), 178 (11), 118 (7).

4.6. Dimroth Rearrangement of 2-[1-Aryl-5-imino-2-phenyl-1*H*-imidazol-4(5*H*)-ylidene]malononitrile (13a) into (*Z*)-2-[4-(Arylimino)-2-phenyl-1*H*-imidazol-5(4*H*)-ylidene]malononitrile (14a). *4.6.1. (Z)-2-[2-Phenyl-4-(phenylimino)-1H-imidazol-5(4H)-ylidene]malononitrile (14a) (Typical procedures, See Table 3). Method A.* A stirred solution of 2-[5-imino-1,2-diphenyl-1*H*-imidazol-4(5*H*)-ylidene]malononitrile (**13a**) (1 g, 3.37 mmol) in MeOH (15 mL) was heated at ca. 67 °C for 1 h and then allowed to cool to ca. 20 °C. Addition of H_2O (30 mL) and filtration of the precipitate gave the title compound **14a** (989.5 mg, 99%), as orange fibers: mp (DSC) onset 254.9 °C, decomp. 256.7 °C (from cyclohexane/DCE, 50:50), identical to that described above.

Method B. To a stirred solution of 2-[5-imino-1,2-diphenyl-1*H*-imidazol-4(5*H*)-ylidene]malononitrile (**13a**) (1 g, 3.37 mmol) in dry DCM (15 mL) at ca. 20 °C, DBU (502 μL, 3.37 mmol) was added. The reaction mixture was then heated at ca. 40 °C for 4 h, protected from moisture with $CaCl_2$ drying tube. The reaction mixture was then extracted (5% HCl) and washed (H_2O), and the organic fraction was dried (Na_2SO_4). Removal of the volatiles followed by addition of MeOH (10 mL), H_2O (30 mL) and filtration of the precipitant gave the title compound **14a** (912.4 mg, 91%) as orange fibers: mp (DSC) onset 254.9 °C, decomp. 256.7 °C (from cyclohexane/DCE, 50:50), identical to that described above.

4.7. Thermal Behavior of 2-[5-Imino-1,2-diphenyl-1*H*-imidazol-4(5*H*)-ylidene]malononitrile (13a). Heating 2-[5-imino-1,2-diphenyl-1*H*-imidazol-4(5*H*)-ylidene]malononitrile (**13**) at ca. 220 °C (Wood's metal bath) for 20 min under Ar atmosphere followed by chromatography (DCM) gave 2-phenyl-6-(phenylamino)pyrimidine-4,5-dicarbonitrile (**22**) (3.4 mg, 11%) as yellow fibers: mp (DSC) onset 237.4 °C, peak max. 238.3 °C (from cyclohexane/DCE, 80:20); (found C, 72.85; H, 3.67; N, 23.39. $C_{18}H_{11}N_5$ requires C, 72.72; H, 3.73; N, 23.56%); R_f 0.42 (DCM); λ_{max}(DCM)/nm 273 inf (log ε 4.59), 292 (4.64), 363 inf (3.76); ν_{max}/cm^{-1} 3298w (NH), 3163w, 3127w, 3065w (Ar CH), 2226w (C≡N), 1611m, 1574m, 1555s, 1495w, 1481w, 1460w, 1429m, 1385m, 1350w, 1290w, 1244w, 1196w, 1173w, 1155w, 1092w, 1070w, 1036w, 1028w, 1018w, 1001w, 937w, 908w, 841w, 806w, 766m; δ_H (500 MHz; $CDCl_3$), 8.37 (2H, d, *J* 7.5, Ar *H*), 7.65 (2H, d, *J* 8.0, Ar *H*), 7.58 (1H, dd, *J* 7.5, 7.5, Ar *H*), 7.50 (4H, dd, *J* 7.8, 7.8, Ar *H*), 7.45 (1H, br s, N*H*), 7.33 (1H, dd, *J* 7.5, 7.5, Ar *H*); δ_C (125 MHz; $CDCl_3$) 166.7 (s), 159.5 (s), 144.4 (s), 135.8 (s), 134.9 (s), 133.2 (d), 129.5 (d), 129.3 (d), 128.9 (d), 126.5 (d), 122.5 (d), 113.6 (C≡N), 112.5 (C≡N), 93.3 (s); *m*/*z* (MALDI-TOF) 299 (MH^+ + 1, 21%), 298 (MH^+, 100%). Further elution (DCM/Et_2O, 95:05) gave (*Z*)-2-[2-phenyl-4-(phenylimino)-1*H*-imidazol-5(4*H*)-ylidene]malononitrile (**14a**) (10.1 mg, 34%) as orange fibers: mp (DSC) decomp. onset 254.9 °C, peak. 256.7 °C (from cyclohexane/DCE, 50:50), identical to that described above. This was followed by traces of 2-phenyl-1*H*-imidazo[4,5-*b*]quinoline-9-carbonitrile (**15a**) as colorless fibers: mp (DSC) decomp. onset 304.7 °C, peak max. 305.1 °C (from cyclohexane/DCE, 50:50), identical to that described above.

4.8. Thermal Behavior of (*Z*)-2-[2-Phenyl-4-(phenylimino)-1*H*-imidazol-5(4*H*)-ylidene]malononitrile (14a). *4.8.1. 2-Phenyl-1H-imidazo[4,5-b]quinoline-9-carbonitrile (15a) (Typical procedure, See Table 4).* An intimate mixture of (*Z*)-2-[2-phenyl-4-(phenylimino)-1*H*-imidazol-5(4*H*)-ylidene]malononitrile (**14a**) (14.6 mg, 0.05 mmol) and diphenyl ether (1 mL) was heated at ca. 280 °C for 4 h. Chromatography (*n*-hexane/DCM, 50:50) of the reaction mixture gave recovered diphenyl ether (1 mL), and further elution (DCM/Et_2O, 90:10) gave the title compound **15a** (13.4 mg, 100%) as colorless fibers: mp (DSC) decomp. onset 304.7 °C, peak max. 305.1 °C; (from *n*-pentane/THF, 90:10); (found C, 75.53; H, 3.62; N, 20.80. $C_{17}H_{10}N_4$ requires C, 75.54; H, 3.73; N, 20.73%); R_f 0.23 (DCM/Et_2O, 90:10); λ_{max}(EtOH)/nm 216 (log ε 4.77), 265 (4.68), 281 inf (4.39), 371 (4.71); ν_{max}/cm^{-1} 3073br,w and 3015br,w (Ar CH and NH), 2887w, 2710w, 2230w (C≡N), 1628m, 1616w, 1593w, 1526m, 1514w, 1481m, 1472m, 1460s, 1402s, 1333s, 1288m, 1240m, 1186w, 1163m, 1138w, 1072w, 1028w, 1001w, 939m, 928w, 880w, 862w, 843w, 787s, 762s; δ_H (500 MHz; TFA-*d*) N*H* deuterium exchanged, 8.42 (1H, d, *J* 8.5, Ar *H*), 8.22−8.20 (3H, m, Ar *H*), 8.11 (1H, dd, *J* 7.8, 7.8, Ar *H*), 7.97 (1H, dd, *J* 7.5, 7.5, Ar *H*), 7.78 (1H, dd, *J* 7.5, 7.5 Ar *H*), 7.63 (2H, dd, *J* 8.0, 8.0 Ar *H*); δ_C (125 MHz; TFA-*d*) 166.6 (s), 150.9 (s), 139.6 (s), 139.3 (d), 137.4 (d), 132.9 (d), 132.50 (d), 132.46 (s), 131.4 (d), 127.9 (d), 126.2 (s), 124.5 (s), 124.2 (d), 112.6 (s, C≡N), 109.2 (s); *m*/*z* (MALDI-TOF) 272 (MH^+ + 1, 18%), 271 (MH^+, 100), 270 (M^+, 15).

4.8.2. 7-Methoxy-2-phenyl-1H-imidazo[4,5-b]quinoline-9-carbonitrile (15b). Similar treatment of (*Z*)-2-[4-(4-methoxyphenylimino)-2-phenyl-1*H*-imidazol-5(4*H*)-ylidene]malononitrile (**14b**) (16.4 mg, 0.05 mmol) gave the title compound **15b** (14.9 mg, 99%) as pale yellow plates: mp (DSC) decomp. onset 309.3 °C, peak max. 309.5 °C; (from *n*-pentane/THF, 90:10); (found C, 71.87; H, 3.97; N, 18.66. $C_{18}H_{12}N_4O$ requires C, 71.99; H, 4.03; N, 18.66%); R_f 0.23 (DCM/Et_2O, 90:10); λ_{max}(EtOH)/nm 226 (log ε 4.68), 253 inf (4.69), 271 (4.83), 372 (4.52), 402 inf (4.27); ν_{max}/cm^{-1} 3069br,w (Ar CH and NH), 2963w, 2920w and 2855w (CH_3), 2224w (C≡N), 1630m, 1601w, 1514m, 1472m, 1460s, 1433w, 1402w, 1336s, 1288w, 1261m, 1242s, 1211m, 1179m, 1148w, 1128w, 1070w, 1041m, 1028w, 997w, 986w, 939m, 849w, 822m, 804w, 783w, 766w; δ_H (500 MHz; TFA-*d*) N*H* deuterium exchanged, 8.27 (2H, d, *J* 8.0 Ar *H*), 8.19 (1H, d, *J* 9.5 Ar *H*), 7.89−7.84 (2H, m, Ar *H*), 7.76−7.72 (3H, m, Ar *H*), 4.11 (3H, s, CH_3); δ_C (125 MHz; TFA-*d*) one quaternary C (s) resonance missing 163.7 (s), 162.8 (s), 146.7 (s), 138.7 (d), 137.5 (s), 132.1 (d), 130.8 (s), 130.58 (d), 130.56 (d), 129.0 (s), 126.5 (d), 123.3 (s), 105.6 (s), 104.3 (d), 57.2 (q); *m*/*z* (MALDI-TOF) 302 (MH^+ + 1, 12%), 301 (MH^+, 100), 300 (M^+, 37), 242 (16), 153 (34).

4.8.3. 7-Methyl-2-phenyl-1H-imidazo[4,5-b]quinoline-9-carbonitrile (15c). Similar treatment of (*Z*)-2-[2-phenyl-4-(*p*-tolylimino)-1*H*-imidazol-5(4*H*)-ylidene]malononitrile (**14c**) (15.6 mg, 0.05 mmol) gave the title compound **15c** (14.8 mg, 99%) as pale yellow plates: mp (DSC) decomp. onset 322.8 °C, peak 323.8 °C; (from *n*-pentane/THF, 90:10); (found C, 75.94; H, 4.26; N, 19.68. $C_{18}H_{12}N_4$ requires C, 76.04; H, 4.25; N, 19.71%); R_f 0.26 (DCM/Et_2O, 90:10); λ_{max}(EtOH)/nm 220 (log ε 4.68), 267 (4.58), 282 inf (4.30), 369 (4.60); ν_{max}/cm^{-1} 3063br,w and 3028br,w (Ar CH and NH), 2967w, 2912w, 2758w, 2224w (C≡N), 1632w, 1618w, 1591w, 1524w, 1514m, 1479s, 1460s, 1404m, 1396m, 1333s, 1288m, 1233m, 1213m, 1202w, 1184w, 1157w, 1148w, 1101w, 1069w, 1034w, 1022w, 974w, 934s, 893w, 868w, 826s, 808m, 779w, 768w; δ_H (500 MHz; TFA-*d*) N*H* deuterium exchanged, 8.23−8.20 (3H, m, Ar *H*), 8.14−8.09 (1H, m, Ar *H*), 8.01−7.96 (1H, m, Ar *H*), 7.80−7.6 (1H, m, Ar *H*), 7.66−7.63 (2H, m, Ar *H*), 2.64 (3H, t, *J* 9.0, CH_3); δ_C (125 MHz; TFA-*d*) 165.5 (s), 149.5 (s), 145.3 (s), 139.5 (d), 138.7 (d), 137.8 (s), 132.0 (d), 131.8 (s), 130.8 (d), 126.2 (s), 126.0 (d), 124.1 (s), 123.3 (d), 112.3 (s, C≡N), 107.8 (s), 21.8 (q); *m*/*z* (MALDI-TOF) 286 (MH^+ + 1, 14%), 285 (MH^+, 100), 284 (M^+, 30).

4.8.4. 7-Fluoro-2-phenyl-1H-imidazo[4,5-b]quinoline-9-carbonitrile (15d). Similar treatment of (*Z*)-2-[5-(4-fluorophenylimino)-2-phenyl-1*H*-imidazol-4(5*H*)-ylidene]malononitrile (**14d**) (15.8 mg, 0.05 mmol) gave the title compound **15d** (14.3 mg, 99%) as pale yellow plates: mp (DSC) decomp. onset 338.5 °C, peak max. 339.1

dx.doi.org/10.1021/jo4013699 | J. Org. Chem. 2013, 78, 8655−8668

°C; (from *n*-pentane/THF, 90:10); (found C, 70.82; H, 3.10; N, 19.38. $C_{17}H_9FN_4$ requires C, 70.83; H, 3.15; N, 19.43%); R_f 0.34 (DCM/Et_2O, 90:10); λ_{max}(EtOH)/nm 218 (log ε 4.76), 266 (4.62), 279 inf (4.38), 366 (4.69); ν_{max}/cm^{-1} 3067br,w and 3010br,w (Ar CH and NH), 2903w, 2228w (C≡N), 1637m, 1597w, 1524m, 1477m, 1458s, 1406s, 1398m, 1333s, 1302w, 1281w, 1236s, 1207w, 1188w, 1157w, 1128w, 1097w, 1088w, 1070w, 1038w, 1028w, 1007w, 974w, 939m, 852m, 824w, 818w, 783m; δ_H (500 MHz; TFA-*d*) N*H* deuterium exchanged, 8.28 (1H, dd, $^3J_{HH}$ 9.5, $^4J_{HF}$ 4.5, Ar *H*), 8.25 (2H, d, *J* 7.5, Ar *H*), 8.05 (1H, dd, $^3J_{HF}$ 7.8, $^4J_{HH}$ 2.3, Ar *H*), 7.89−7.84 (2H, m, Ar *H*), 7.71 (2H, dd, *J* 8.0, 8.0, Ar *H*); δ_C (125 MHz; TFA-*d*) 165.9 (s), 163.6 (s, $^1J_{CF}$ 232.5, *C*F), 148.1 (s), 139.4 (s), 139.3 (d), 132.2 (d), 130.8 (d), 130.6 (s), 128.9 (d, $^3J_{CF}$ 10.0, CHCHCF), 127.9 (s, $^3J_{CF}$ 10.0, CCHCF), 126.7 (d, $^2J_{CF}$ 27.5, CHCF), 122.6 (s), 112.1 (s, C≡N), 111.1 (d, $^2J_{CF}$ 25.0, CHCF), 106.5 (s, $^3J_{CF}$ 6.3, CCHCF); *m*/*z* (MALDI-TOF) 290 (MH^+ + 1, 12%), 289 (MH^+, 100), 288 (M^+, 21), 153 (4).

4.8.5. 7-Chloro-2-phenyl-1H-imidazo[4,5-b]quinoline-9-carbonitrile (15e). Similar treatment of (*Z*)-2-[5-(4-chlorophenylimino)-2-phenyl-1*H*-imidazol-4(5*H*)-ylidene]malononitrile (**14e**) (16.7 mg, 0.05 mmol) gave the title compound **15e** (15 mg, 98%) as pale yellow plates: mp (DSC) decomp. onset 356.4 °C, peak max. 357.8 °C; (from *n*-pentane/THF, 90:10); (found C, 66.93; H, 2.98; N, 18.26. $C_{17}H_9ClN_4$ requires C, 67.00; H, 2.98; N, 18.39%); R_f 0.38 (DCM/Et_2O, 90:10); λ_{max}(EtOH)/nm 206 (log ε 4.55), 226 (4.82), 235 inf (4.78), 272 (4.79), 283 inf (4.68), 369 (4.79), 385 inf (4.62), 414 inf (4.21); ν_{max}/cm^{-1} 3194br,w, 3156br,w and 3069br,w (Ar CH and NH), 2903w, 2708w, 2241w (C≡N), 1628m, 1603w, 1589w, 1529m, 1499m, 1476s, 1458s, 1443w, 1406s, 1391s, 1333s, 1317m, 1294m, 1277w, 1231m, 1202m, 1188m, 1157w, 1134w, 1125w, 1082w, 1026w, 1003w, 980w, 949m, 935w, 878w, 864w, 829s, 785m; δ_H (500 MHz; TFA-*d*) N*H* deuterium exchanged, 8.44 (1H, d, *J* 1.5, Ar *H*), 8.29 (2H, d, *J* 7.5, Ar *H*), 8.22 (1H, d, *J* 9.0, Ar *H*), 8.07 (1H, dd, *J* 9.0, 2.0 Ar *H*), 7.89 (1H, dd, *J* 7.5, 7.5 Ar *H*), 7.74 (2H, dd, *J* 8.0, 8.0 Ar *H*); δ_C (125 MHz; TFA-*d*) 164.0 (s), 148.8 (s), 140.4 (s), 140.2 (s), 139.4 (d), 137.3 (d), 132.2 (d), 130.97 (s), 130.94 (d), 127.1 (d), 126.9 (s), 125.9 (d), 122.9 (s), 112.0 (s, C≡N), 106.4 (s); *m*/*z* (MALDI-TOF) 307 (MH^+ + 2, 33%), 306 (MH^+ + 1, 18), 305 (MH^+, 100), 304 (M^+, 11).

4.8.6. 6,7-Dichloro-2-phenyl-1H-imidazo[4,5-b]quinoline-9-carbonitrile (15f) and 7,8-Dichloro-2-phenyl-1H-imidazo[4,5-b]-quinoline-9-carbonitrile (15g). Similar treatment of (*Z*)-2-[5-(3,4-dichlorophenylimino)-2-phenyl-1*H*-imidazol-4(5*H*)-ylidene]-malononitrile (**14f**) (18.3 mg, 0.05 mmol) gave 6,7-dichloro-2-phenyl-1*H*-imidazo[4,5-*b*]quinoline-9-carbonitrile (**15f**) (14.2 mg, 84%) as colorless needles: mp (DSC) decomp. onset 323.6 °C, peak max. 324.4 °C; (from *n*-pentane/THF, 90:10); (found C, 60.09; H, 2.29; N, 16.46. $C_{17}H_8Cl_2N_4$ requires C, 60.20; H, 2.38; N, 16.52%); R_f 0.63 (DCM/Et_2O, 90:10); λ_{max}(EtOH)/nm 205 (log ε 4.59), 231 inf (4.79), 244 (4.85), 277 (4.87), 290 inf (5.02), 367 inf (4.76), 376 (4.79), 389 inf (4.62), 422 inf (4.18); ν_{max}/cm^{-1} 3096br,w (Ar CH and NH), 2978w, 2879w, 2228w (C≡N), 1628m, 1587w, 1528m, 1474m, 1460s, 1439w, 1408m, 1389s, 1335m, 1313w, 1288m, 1242m, 1223m, 1204m, 1183w, 1119m, 1101w, 1070w, 1047s, 1028w, 986m, 941m, 928w, 876s, 841w, 816w, 787m, 764w; δ_H (500 MHz; TFA-*d*) N*H* deuterium exchanged, 8.51 (1H, s, Ar *H*), 8.38 (1H, s, Ar *H*), 8.25 (2H, d, *J* 7.5, Ar *H*), 7.88 (1H, dd, *J* 7.5, 7.5, Ar *H*), 7.72 (2H, dd, *J* 8.0, 8.0, Ar *H*); δ_C (125 MHz; TFA-*d*) 161.2 (s), 146.7 (s), 140.7 (s), 140.0 (s), 137.8 (d), 137.4 (s), 130.5 (d), 129.1 (d), 128.0 (s), 125.8 (d), 125.5 (d), 123.6 (s), 120.4 (s), 110.1 (s, C≡N), 104.0 (s); *m*/*z* (MALDI-TOF) 343 (MH^+ + 4, 3%), 342 (MH^+ + 3, 7), 341 (MH^+ + 2, 54), 340 (MH^+ + 1, 13), 339 (MH^+, 100), 338 (12), 219 (56). Further elution (DCM/Et_2O, 90:10) gave 7,8-dichloro-2-phenyl-1*H*-imidazo[4,5-*b*]quinoline-9-carbonitrile (**15g**) (2.1 mg, 12%) as colorless plates: mp (DSC) decomp. onset 358.3 °C, peak max. 362.1 °C; (from *n*-pentane/THF, 90:10); (found C, 60.28; H, 2.42; N, 16.34. $C_{17}H_8Cl_2N_4$ requires C, 60.20; H, 2.38; N, 16.52%); R_f 0.50 (DCM/Et_2O, 90:10); λ_{max}(EtOH)/nm 209 (log ε 4.87), 225 inf (4.73), 277 (4.39), 365 (3.94), 378 (3.94); ν_{max}/cm^{-1} 3173br,w (Ar CH and NH), 2234w (C≡N), 1624w, 1609w, 1574w, 1526m, 1479s, 1456s, 1435w, 1393s, 1375s, 1317m, 1300m, 1285w, 1194s, 1153m, 1103w, 1049w, 1038w, 1024w, 1001w, 986w, 947w, 924m, 881w, 824s, 814s, 781m, 752w; δ_H (500 MHz; TFA-*d*) N*H* deuterium exchanged, 8.41 (2H, d, *J* 8.0, Ar *H*), 8.19 (1H, d, *J* 9.0, Ar *H*), 8.12 (1H, d, *J* 9.5, Ar .*H*), 7.95 (1H, dd, *J* 7.8, 7.8, Ar *H*), 7.78 (2H, dd, *J* 7.8, 7.8, Ar *H*); δ_C (125 MHz; TFA-*d*) one quaternary C (s) resonance missing 163.2 (s), 147.2 (s), 145.1 (s), 140.1 (d), 139.8 (s), 136.8 (d), 133.3 (s), 132.6 (d), 131.5 (d), 130.8 (s), 128.0 (d), 125.0 (s), 122.1 (s), 104.6 (s); *m*/*z* (MALDI-TOF) 343 (MH^+ + 4, 3%), 342 (MH^+ + 3, 5), 341 (MH^+ + 2, 64), 340 (MH^+ + 1, 24), 339 (MH^+, 100), 338 (12), 219 (13).

4.8.7. 7-Bromo-2-phenyl-1H-imidazo[4,5-b]quinoline-9-carbonitrile (15h). Similar treatment of (*Z*)-2-[5-(4-bromophenylimino)-2-phenyl-1*H*-imidazol-4(5*H*)-ylidene]malononitrile (**14h**) (18.8 mg, 0.05 mmol) gave the title compound **15h** (17.1 mg, 98%) as colorless plates: mp (DSC) decomp. onset 337.6 °C, peak max. 338.6 °C; (from *n*-pentane/THF, 90:10); (found C, 58.35; H, 2.67; N, 15.96. $C_{17}H_9BrN_4$ requires C, 58.47; H, 2.60; N, 16.05%); R_f 0.43 (DCM/Et_2O, 90:10); λ_{max}(EtOH)/nm 229 inf (log ε 4.73), 235 (4.74), 273 (4.75), 283 inf (4.64), 369 (4.77), 412 inf (3.94); ν_{max}/cm^{-1} 3069br,w (Ar CH and NH), 2878w, 2735w, 2222w (C≡N), 1628m, 1599w, 1589w, 1529m, 1495m, 1476s, 1464s, 1406s, 1393s, 1333s, 1296m, 1234m, 1202m, 1188m, 1165w, 1132w, 1126w, 1105w, 1070w, 1040s, 972w, 935m, 918w, 874s, 858m, 818s, 781m; δ_H (500 MHz; TFA-*d*) N*H* deuterium exchanged, 8.61 (1H, s, Ar *H*), 8.27 (2H, d, *J* 8.0, Ar *H*), 8.18 (1H, d, *J* 9.5, Ar *H*), 8.11 (1H, d, *J* 9.0, Ar *H*), 7.87 (1H, dd, *J* 7.5, 7.5, Ar *H*), 7.72 (2H, dd, *J* 7.8, 7.8, Ar *H*); δ_C (125 MHz; TFA-*d*) one quaternary C (s) resonance missing 162.7 (s), 148.9 (s), 140.4 (s), 139.9 (d), 139.3 (d), 132.2 (d), 130.94 (s), 130.89 (d), 129.3 (d), 127.7 (s), 127.1 (s), 126.7 (d), 122.9 (s), 112.0 (s, C≡N), 106.3 (s); *m*/*z* (MALDI-TOF) 351 (MH^+ + 2, 49%), 350 (MH^+ + 1, 14), 349 (MH^+, 100), 312 (25), 270 (30), 246 (8), 219 (37), 105 (6).

4.8.8. 7-Iodo-2-phenyl-1H-imidazo[4,5-b]quinoline-9-carbonitrile (15i). Similar treatment of (*Z*)-2-[5-(4-iodophenylimino)-2-phenyl-1*H*-imidazol-4(5*H*)-ylidene]malononitrile (**14i**) (21.2 mg, 0.05 mmol) gave the title compound **15i** (19.3 mg, 98%) as pale colorless needles: mp (DSC) decomp. onset 342.2 °C, peak max. max. 342.8 °C; (from *n*-pentane/THF, 90:10); (found C, 51.50; H, 2.23; N, 14.05. $C_{17}H_9IN_4$ requires C, 51.54; H, 2.29; N, 14.14%); R_f 0.30 (DCM/Et_2O, 90:10); λ_{max}(EtOH)/nm 207 (log ε 4.62), 227 (4.84), 249 inf (4.67), 272 (4.82), 285 inf (4.64), 374 (4.81), 386 (4.64); ν_{max}/cm^{-1} 3098br,w (Ar CH and NH), 2911w, 2737w, 2224w (C≡N), 1697m, 1630m, 1597w, 1528m, 1490m, 1477s, 1460s, 1404s, 1391s, 1333s, 1315m, 1294m, 1233m, 1204m, 1194w, 1136w, 1103w, 1067w, 1028w, 1001w, 966w, 937s, 872m, 824s, 785s, 760m; δ_H (500 MHz; TFA-*d*) N*H* deuterium exchanged, 8.92 (1H, s, Ar *H*), 8.44 (1H, d, *J* 9.0, Ar *H*), 8.34 (2H, d, *J* 8.0, Ar *H*), 8.03 (1H, d, *J* 9.0, Ar *H*), 7.95 (1H, dd, *J* 7.5, 7.5, Ar *H*), 7.79 (2H, dd, *J* 7.8, 7.8, Ar *H*); δ_C (125 MHz; TFA-*d*) 164.6 (s), 149.1 (s), 145.5 (d), 140.4 (s), 139.3 (d), 136.0 (d), 132.2 (d), 131.0 (s), 130.9 (d), 127.2 (s), 125.9 (d), 123.1 (s), 112.1 (s, C≡N), 106.2 (s), 98.1 (s); *m*/*z* (MALDI-TOF) 398 (MH^+ + 1, 8%), 397 (MH^+, 100), 270 (63), 246 (3), 219 (43), 105 (4).

4.9. *N*-Methylation of 2-Phenyl-1*H*-imidazo[4,5-*b*]quinoline-9-carbonitrile (15a). To a stirred solution of 2-phenyl-1*H*-imidazo-[4,5-*b*]quinoline-9-carbonitrile (**15a**) (13.5 mg, 0.05 mmol) in dry THF (1 mL) at ca. 20 °C was added NaH (2.4 mg, 0.1 mmol) and dimethyl sulfate (9.5 μL, 0.1 mmol). The mixture was heated at ca. 66 °C for 26 h and then allowed to cool to ca. 20 °C. Removal of the volatiles followed by chromatography (DCM/Et_2O, 90:10) of the residue gave 3-methyl-2-phenyl-3*H*-imidazo[4,5-*b*]quinoline-9-carbonitrile (**27**) (13.5 mg, 95%) as colorless needles: mp (DSC) onset 204.0 °C, peak max. 204.4 °C (from *n*-pentane/DCE, 70:30); (found C, 75.90; H, 4.36; N, 19.69. $C_{18}H_{12}N_4$ requires C, 76.04; H, 4.25; N, 19.71%); R_f 0.68 (DCM/Et_2O, 90:10); λ_{max}(EtOH)/nm 217 (log ε 4.90), 263 (4.80), 357 (4.76); ν_{max}/cm^{-1} 3063w (Ar CH), 2995w, 2953w, 2922w and 2851w (CH_3), 2228w (C≡N), 1612w, 1584w, 1516w, 1484m, 1466s, 1447m, 1435m, 1396m, 1335s, 1286m, 1258w, 1232w, 1204w, 1182w, 1169m, 1157w, 1107w, 1076w, 1053w, 1022w, 945w, 930w, 860w, 849w, 795w, 779m, 764s; δ_H (500 MHz; TFA-*d*)

dx.doi.org/10.1021/jo4013699 | J. Org. Chem. 2013, 78, 8655−8668

8.44 (1H, d, *J* 8.5, Ar *H*), 8.39 (1H, d, *J* 8.0, Ar *H*), 8.06 (1H, dd, *J* 7.8, 7.8, Ar *H*), 7.99−7.96 (3H, m, Ar *H*), 7.90 (1H, dd, *J* 7.5, 7.5, Ar *H*), 7.77 (2H, dd, *J* 8.0, 8.0, Ar *H*), 4.35 (3H, s, CH_3); δ_C (125 MHz; TFA-*d*) one quaternary C (s) resonance missing 158.6 (s), 146.6 (s), 144.4 (s), 136.1 (d), 132.9 (d), 131.1 (d), 130.4 (d), 129.7 (d), 129.5 (d), 125.8 (s), 124.6 (d), 123.6 (s), 120.1 (s), 102.5 (s), 31.4 (q, CH_3); *m*/*z* (MALDI-TOF) 286 (MH^+ + 1, 11%), 285 (MH^+, 100), 284 (M^+, 93). Further elution (DCM/Et_2O, 90:10) gave 4-methyl-2-phenyl-4*H*-imidazo[4,5-*b*]quinoline-9-carbonitrile (**28**) (1.1 mg, 1%) as yellow plates: mp (DSC) onset 254.9 °C, peak max. 255.6 °C (from *n*-pentane/DCE, 70:30); (found C, 75.88; H, 4.29; N, 19.62. $C_{18}H_{12}N_4$ requires C, 76.04; H, 4.25; N, 19.71%); R_f 0.54 (DCM/Et_2O, 90:10); λ_{max}(EtOH)/nm 228 (log ε 4.71), 248 inf (4.42), 264 inf (4.31), 381 (4.67), 389 inf (4.59); ν_{max}/cm^{-1} 3069w (Ar CH), 2951w and 2922w (CH_3), 2222w (C≡N), 1624w, 1593m, 1578w, 1483m, 1454s, 1431s, 1412m, 1393w, 1369m, 1335m, 1308w, 1285m, 1256s, 1217m, 1171m, 1136w, 1105w, 1074m, 1066m, 1022w, 1011w, 935m, 856w, 797w, 760m; δ_H (500 MHz; TFA-*d*) 8.54 (1H, d, *J* 8.5, Ar *H*), 8.46 (2H, d, *J* 7.5, Ar *H*), 8.37 (1H, d, *J* 9.0, Ar *H*), 8.25 (1H, ddd, *J* 8.0, 8.0, 1.0, Ar *H*), 8.06 (1H, dd, *J* 7.8, 7.8, Ar *H*), 7.79 (1H, dd, *J* 7.5, 7.5, Ar *H*), 7.66 (2H, dd, *J* 7.8, 7.8 Ar *H*), 4.85 (3H, s, CH_3); δ_C (125 MHz; TFA-*d*) 169.3 (s), 156.0 (s), 138.4 (d), 138.0 (s), 137.2 (d), 134.7 (s), 131.8 (d), 131.7 (d), 131.6 (d), 128.8 (d), 126.7 (s), 125.2 (s), 119.2 (d), 112.8 (s, *C*≡N), 107.4 (s), 37.7 (q, CH_3); *m*/*z* (MALDI-TOF) 286 (MH^+ + 1, 13%), 285 (MH^+, 100), 284 (M^+, 9).

4.10. Thermolysis of (*Z*)-2-[1-Methyl-2-phenyl-4-(phenylimino)-1*H*-imidazol-5(4*H*)-ylidene]malononitrile (16). An intimate mixture of (*Z*)-2-[1-methyl-2-phenyl-4-(phenylimino)-1*H*-imidazol-5(4*H*)-ylidene]malononitrile (**16**) (14.2 mg, 0.05 mmol) and diphenyl ether (1 mL) was heated at ca. 250 °C for 4 h. Chromatography (*n*-hexane/DCM, 50:50) of the reaction mixture gave recovered diphenyl ether (1 mL) and further elution (DCM/Et_2O, 90:10) gave 1-methyl-2-phenyl-1*H*-imidazo[4,5-*b*]quinoline-9-carbonitrile (**26**) (12.9 mg, 91%) as colorless prisms: mp (DSC) onset 226.4 °C, peak max. 227.3 °C; (from *n*-pentane/THF, 90:10); (found C, 75.92; H, 4.35; N, 19.68. $C_{18}H_{12}N_4$ requires C, 76.04; H, 4.25; N, 19.71%); R_f 0.34 (DCM/Et_2O, 90:10); λ_{max}(EtOH)/nm 218 (log ε 4.92), 263 (4.83), 358 (4.77); ν_{max}/cm^{-1} 3086w (Ar CH), 2951w (CH_3), 2220w (C≡N), 1605w, 1524m, 1479m, 1462m, 1443m, 1400m, 1366s, 1337s, 1292m, 1246m, 1238m, 1211w, 1184w, 1163w, 1136w, 1078m, 1055w, 1047w, 1022w, 1015w, 984w, 962w, 943w, 932w, 881w, 870w, 860w, 798w, 793w, 785s, 773s; δ_H (500 MHz; TFA-*d*) 8.66 (1H, d, *J* 8.5, Ar *H*), 8.39 (1H, d, *J* 8.5, Ar *H*), 8.28 (1H, dd, *J* 7.9, 7.9, Ar *H*), 8.15 (1H, dd, *J* 7.8, 7.8, Ar *H*), 7.99 (2H, d, *J* 7.0, Ar *H*), 7.93 (1H, dd, *J* 7.5, 7.5, Ar *H*), 7.82 (2H, dd, *J* 8.0, 8.0, Ar *H*), 4.59 (3H, s, CH_3); δ_C (125 MHz; TFA-*d*) 167.3 (s), 148.7 (s), 141.2 (s), 137.7 (d), 137.5 (d), 133.1 (d), 132.2 (d), 132.0 (d), 131.8 (s), 127.7 (d), 126.9 (s), 125.1 (d), 123.9 (s), 112.3 (s, C≡N), 109.5 (s), 36.2 (q, CH_3); *m*/*z* (MALDI-TOF) 286 (MH^+ + 1, 18%), 285 (MH^+, 100), 284 (M^+, 24), 283 (13), 118 (7), 105 (6).

4.11. Thermolysis of (*Z*)-2-(1-Methyl-2-phenyl-5-(phenylimino)-1*H*-imidazol-4(5*H*)-ylidene)malononitrile (17). An intimate mixture of (*Z*)-2-[1-methyl-2-phenyl-5-(phenylimino)-1*H*-imidazol-4(5*H*)-ylidene]malononitrile (**17**) (14.2 mg, 0.05 mmol) and diphenyl ether (1 mL) was heated at ca. 250 °C for 4 h. Chromatography (*n*-hexane/DCM, 50:50) of the reaction mixture gave recovered diphenyl ether (1 mL), and further elution (DCM/Et_2O, 90:10) gave 1-methyl-2-phenyl-1*H*-imidazo[4,5-*b*]quinoline-9-carbonitrile (**27**) (14.4 mg, 93%) as colorless prisms: mp (DSC) onset 204.0 °C, peak max. 204.4 °C (from *n*-pentane/DCE, 70:30), identical to that described above.

4.12. X-ray Crystallographic Studies. Data were collected on an diffractometer, equipped with a CCD area detector utilizing Cu Kα radiation (λ = 1.5418 Å) for compounds **13a** (CCDC-943799), **14a** (CCDC-943800), and **16** (CCDC-943801), while Mo Kα radiation (λ = 0.71073 Å) was used for compound **22** (CCDC-943798). Suitable crystals were attached to glass fibers using paratone-N oil and transferred to a goniostat where they were cooled for data collection. Unit cell dimensions were determined and refined by using 2161 ($3.45 \le \theta \le 66.97°$), 2247 ($3.33 \le \theta \le 71.89°$), 2367 ($4.97 \le \theta \le 66.97°$), and 2113 ($2.98 \le \theta \le 2\ 8.90°$) reflections for compounds **13a**, **14a**, **16**, and **22**, respectively. Empirical absorption corrections (multiscan based on symmetry-related measurements) were applied using CrysAlis RED software.[60] The structures were solved by direct method and refined on F^2 using full-matrix least-squares using SHELXL97.[61] Software packages used were CrysAlis CCD[60] for data collection, CrysAlis RED[60] for cell refinement and data reduction, WINGX for geometric calculations,[62] and DIAMOND[63] for molecular graphics. The non-H atoms were treated anisotropically. The hydrogen atoms were placed in calculated, ideal positions and refined as riding on their respective carbon atoms.

*4.12.1. Crystal Refinement Data for Compound **13a**.* Yellow crystals, $C_{18}H_{11}N_5$, *M* = 297.32, orthorhombic, space group *Pbca*, *a* = 6.7212(5) Å, *b* = 16.922(2) Å, *c* = 25.652(3) Å, α = 90°, β = 90°, γ = 90°, *V* = 2917.5(5) Å^3, *Z* = 8, *T* = 100(2) K, ρ_{calcd} = 1.354 g cm^{-3}, $2\theta_{max}$ = 67. Refinement of 215 parameters on 2584 independent reflections out of 6039 measured reflections (R_{int} = 0.0374) led to R_1 = 0.0541 ($I > 2\sigma(I)$), wR_2 = 0.1703 (all data), and *S* = 1.082 with the largest difference peak and hole of 0.324 and −0.263 e^{-3}, respectively.

*4.12.2. Crystal Refinement Data for Compound **14a**.* Orange crystals/rods, $C_{18}H_{11}N_5$, *M* = 297.32, orthorhombic, space group *Pbcn*, *a* = 23.5138(7) Å, *b* = 13.2286(4) Å, *c* = 9.4729(3) Å, α = 90°, β = 90°, γ = 90°, *V* = 2946.59(16) Å^3, *Z* = 8, *T* = 100(2) K, ρ_{calcd} = 1.340 g cm^{-3}, $2\theta_{max}$ = 67. Refinement of 212 parameters on 2632 independent reflections out of 6161 measured reflections (R_{int} = 0.0222) led to R_1 = 0.0359 ($I > 2\sigma(I)$), wR_2 = 0.0977 (all data), and *S* = 1.099 with the largest difference peak and hole of 0.211 and −0.186 e^{-3}, respectively.

*4.12.3. Crystal Refinement Data for Compound **16**.* Orange crystals/rods, $C_{19}H_{13}N_5$, *M* = 311.34, monoclinic, space group *P*2/*c*, *a* = 18.0008(18) Å, *b* = 12.1839(12) Å, *c* = 14.6705(19) Å, α = 90°, β = 108.737(12)°, γ = 90°, *V* = 3047.0(6) Å^3, *Z* = 8, *T* = 100(2) K, ρ_{calcd} = 1.357 g cm^{-3}, $2\theta_{max}$ = 67. Refinement of 217 parameters on 2688 independent reflections out of 5111 measured reflections (R_{int} = 0.0180) led to R_1 = 0.0538 ($I > 2\sigma(I)$), wR_2 = 0.1536 (all data), and *S* = 1.041 with the largest difference peak and hole of 0.394 and −0.296 e^{-3}, respectively.

*4.12.4. Crystal Refinement Data for Compound **22**.* Green crystals, $C_{18}H_{11}N_5$, *M* = 297.32, monoclinic, space group *P*2$_1$/*c*, *a* = 8.5353(6) Å, *b* = 14.8828(10) Å, *c* = 11.7854 (8) Å, α = 90°, β = 104.911(7)°, γ = 90°, *V* = 1446.68(17) Å^3, *Z* = 4, *T* = 100(2) K, ρ_{calcd} = 1.365 g cm^{-3}, $2\theta_{max}$ = 25. Refinement of 211 parameters on 2540 independent reflections out of 5481 measured reflections (R_{int} = 0.0290) led to R_1 = 0.0432 ($I > 2\sigma(I)$), wR_2 = 0.1153 (all data), and *S* = 1.066 with the largest difference peak and hole of 0.197 and −0.209 e^{-3}, respectively.

Crystallographic data for compounds **13a**, **14a**, **16**, and **22** have been deposited with the Cambridge Crystallographic Data Centre with deposit numbers CCDC-943799, CCDC-943800, CCDC-943801, and CCDC-943798, respectively. These data can be obtained free of charge via www.ccdc.cam.ac.uk/data_request/cif (or from the Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge CB2 1EZ, U.K.; fax +44 1223 336033; or e-mail deposit@ccdc.cam.ac.uk).

■ ASSOCIATED CONTENT

Supporting Information

Copies of 1D ^{1}H and ^{13}C NMR spectra of all new compounds, 2D NOESY ^{1}H NMR spectra of compounds **17**, **26**, **27**, and **28**, and UV−vis spectra of compounds **14a** (Figure S3), **16** (Figure S5), and **17** (Figure S6). X-ray structures for compounds **13a** (Figure S1), **14a** (Figure S2), **16** (Figure S4), and **22** (Figure S7). Structure elucidation discussion for compounds **12a**−**15a** and **22**. Crystal data (CIF). This material is available free of charge via the Internet at http://pubs.acs.org.

■ AUTHOR INFORMATION

Corresponding Author

*E-mail: koutenti@ucy.ac.cy.

Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

The authors wish to thank the Cyprus Research Promotion Foundation [Grant No. NEKYΠ/0308/02] and the following organizations and companies in Cyprus for generous donations of chemicals and glassware: the State General Laboratory, the Agricultural Research Institute, the Ministry of Agriculture, Biotronics, Ltd., Medisell, Ltd., and MedoChemie, Ltd. Furthermore, we thank the A.G. Leventis Foundation for helping to establish the NMR facility in the University of Cyprus.

■ REFERENCES

(1) Heckert, R. E.; Little, E. L. Jr. US Pat. 2,794,824 (1957).
(2) Cairns, T. L.; Carboni, R. A.; Coffman, D. D.; Engelhardt, V. A.; Heckert, R. E.; Little, E. L.; McGeer, E. G.; McKusick, B. C.; Middleton, W. J.; Scribner, R. M.; Theobald, C. W.; Winberg, H. E. *J. Am. Chem. Soc.* **1958**, *80*, 2775−2778.
(3) Webster, O. W. *J. Polym. Sci., Part A: Polym. Chem.* **2001**, *40*, 210−221.
(4) Merrifield, R. E.; Phillips, W. D. *J. Am. Chem. Soc.* **1958**, *80*, 2778−2782.
(5) Bruni, P.; Tosi, G. *Gazz. Chim. Ital.* **1997**, *127*, 435−459.
(6) Williams, J. K. *J. Am. Chem. Soc.* **1959**, *81*, 4013−4015.
(7) Fatiadi, A. J. *Synthesis* **1987**, 749−789.
(8) Van Dyke, J. W., Jr; Snyder, H. R. *J. Org. Chem.* **1962**, *27*, 3888−3890.
(9) Berk, H. C.; Franz, J. E. *J. Org. Chem.* **1979**, *44*, 2395−2400.
(10) Koutentis, P. A.; Rees, C. W. *J. Chem. Soc., Perkin Trans. 1* **1999**, 111−117.
(11) Hecht, S. M.; Werner, D.; Traficante, D. D.; Sundaralingam, M.; Prusiner, P.; Ito, T.; Sakurai, T. *J. Org. Chem.* **1975**, *40*, 1815−1822.
(12) Earl, R. A.; Pugmire, R. J.; Revankar, G. R.; Townsend, L. B. *J. Org. Chem.* **1975**, *40*, 1822−1828.
(13) Dhar, D. N. *Chem. Rev.* **1967**, *67*, 611−622.
(14) Ciganik, E.; Linn, W. J.; Webster, O. W. *The Chemistry of the Cyano Group*; Rappoport, Z., Ed.; Interscience: London, 1970; pp 423−638.
(15) Freeman, F. *Chem. Rev.* **1980**, *80*, 329−350.
(16) Fatiadi, A. J. *Synthesis* **1986**, 249−284.
(17) Fatiadi, A. J. *Synthesis* **1987**, 959−978.
(18) Kaim, W.; Moscherosch, M. *Coord. Chem. Rev.* **1994**, *129*, 157−193.
(19) Chetkina, L. A.; Bel'skiĭ, V. K. *Crystallogr. Rep.* **2002**, *47*, 581−602.
(20) Zefirov, N. S.; Makhon'kov, D. I. *Russ. Chem. Rev.* **1980**, *49*, 337−356.
(21) McKusick, B. C.; Heckert, R. E.; Cairns, T. L.; Coffman, D. D.; Mower, H. F. *J. Am. Chem. Soc.* **1958**, *80*, 2806−2815.
(22) Ladilina, E. Yu.; Semenov, V. V.; Kurskii, Yu. A.; Khorshev, S. Ya.; Domrachev, G. A. *Russ. J. Org. Chem.* **2004**, *40*, 1258−1264.
(23) Al-Afaleq, E. I.; Abubshait, S. A. *Molecules* **2001**, *6*, 621−638.
(24) Eremkin, A. V.; Ershov, O. V.; Kayukov, Ya. S.; Sheverdov, V. P.; Nasakin, O. E.; Tafeenko, V. A.; Nurieva, E. V. *Tetrahedron Lett.* **2006**, *47*, 1445−1447.
(25) Christoforou, I. C.; Koutentis, P. A.; Michaelidou, S. S. *ARKIVOC* **2006**, *7*, 207−223.
(26) Christoforou, I. C.; Koutentis, P. A.; Rees, C. W. *J. Chem. Soc., Perkin Trans. 1* **2002**, 1236−1241.
(27) Koutentis, P. A.; Rees, C. W. *J. Chem. Soc., Perkin Trans. 1* **2000**, 1089−1094.
(28) Koutentis, P. A.; Rees, C. W. *J. Chem. Soc., Perkin Trans. 1* **2000**, 1081−1088.
(29) Koutentis, P. A.; Rees, C. W. *J. Chem. Soc., Perkin Trans. 1* **1998**, 2505−2509.
(30) Koutentis, P. A.; Mirallai, S. I. *Tetrahedron* **2010**, *66*, 5134−5139.
(31) Hwang, B. H.; Choi, E. B.; Lee, H. K.; Yang, H. C.; Chung, B. Y.; Pak, C. S. *Synthesis* **2008**, 3569−3578.
(32) Narang, K. S.; Rây, J. N. *J. Chem. Soc.* **1931**, 976−980.
(33) Grivas, S.; Schuisky, P. *Heterocycles* **1998**, *48*, 1575−1580.
(34) Redhouse, A. D.; Thompson, R. J.; Wakefield, B. J.; Wardell, J. A. *Tetrahedron* **1992**, *48*, 7619−7628.
(35) Martin, T.; Ulrich, W.-R.; Boer, R.; Graedler, U. WO Pat. 2,004,076,451 (2004).
(36) Zhu, Z.; Lippa, B.; Drach, J. C.; Townsend, L. B. *J. Med. Chem.* **2000**, *43*, 2430−2437.
(37) Rahimizadeh, M.; Pordel, M.; Bakavoli, M.; Eshghi, H. *Dyes Pigm.* **2010**, *86*, 266−270.
(38) Fishwick, C. W. W.; Jones, D. W. In *The Chemistry of Quinonoid Compounds*; Patai, S., Rappoport, Z., Ed.; John Wiley and Sons, Ltd.: New York, 1988; Vol. *2*, p 403−453.
(39) Alves, M. J.; Carvalho, M. A.; Proença, M. F. J. R. P.; Booth, B. L.; Pritchard, R. G. *J. Heterocycl. Chem.* **1999**, *36*, 193−199.
(40) Nelson, K. E.; Levy, M.; Miller, S. L. *Proc. Natl. Acad. Sci. U. S. A.* **2000**, *97*, 3868−3871.
(41) Zaki, M. E. A.; Proença, M. F. *Tetrahedron* **2011**, *67*, 755−762.
(42) Booth, B. L.; Dias, A. M.; Proença, M. F.; Zaki, M. E. A. *J. Org. Chem.* **2001**, *66*, 8436−8441.
(43) Alves, M. J.; Booth, B. L.; Carvalho, M. A.; Dias, A. M.; Pritchard, R. G.; Proença, M. F. J. R. P. *J. Chem. Res., Synop.* **1996**, 212; *J. Chem. Res., Miniprint* **1996**, 1101.
(44) L'abbé, G. *J. Heterocycl. Chem.* **1984**, *21*, 627−638.
(45) Michaelidou, S. S.; Koutentis, P. A. *Synthesis* **2009**, 4167−4174.
(46) Majumder, S.; Gipson, K. R.; Odom, A. L. *Org. Lett.* **2009**, *11*, 4720−4723.
(47) El Kharrat, S.; Skander, M.; Dahmani, A.; Laurent, P.; Blancou, H. *J. Org. Chem.* **2005**, *70*, 8327−8331.
(48) Panda, K.; Siddiqui, I.; Mahata, P. K.; Ila, H.; Junjappa, H. *Synlett* **2004**, 449−452.
(49) Palacios, F.; Aparicio, D.; Vicario, J. *Eur. J. Org. Chem.* **2002**, 4131−4136.
(50) Ono, M.; Todoriki, R.; Tamura, S. *Chem. Pharm. Bull.* **1986**, *34*, 463−470.
(51) McNab, H.; Murray, M. E.-A. *J. Chem. Soc., Perkin Trans. 1* **1984**, 1565−1568.
(52) Knorr, R.; Weiß, A. *Chem. Ber.* **1981**, *114*, 2104−2115.
(53) Maulding, D. R. *J. Heterocycl. Chem.* **1988**, *25*, 1777−1779.
(54) Sanna, P.; Carta, A.; Paglietti, G. *Heterocycles* **1999**, *51*, 2171−2181.
(55) Swaminathan, K. S.; Sai Ganesh, R.; Venkatachalam, C. S.; Balasubramanian, K. K. *Tetrahedron Lett.* **1983**, *24*, 3653−3656.
(56) Karthikeyan, P.; Meena Rani, A.; Saiganesh, R.; Balasubramanian, K. K.; Kabilan, S. *Tetrahedron* **2009**, *65*, 811−821.
(57) Bespalov, B. P.; Abolin, A. G.; Bel'skii, V. K.; Zavodnik, V. E.; Sobolev, A. N.; Chetkina, L. A. *Zh. Org. Khim.* **1991**, *27*, 836−845.
(58) Harwood, L. M. *Aldrichimica Acta* **1985**, *18*, 25−25.
(59) Carboni, R. A. *Org. Synth.* **1963**, *4* (Coll.), 877−880.
(60) *CrysAlis CCD and CrysAlis RED*, Version 1.171.32.15; Oxford Diffraction, Ltd.: Abingdon, Oxford, England, 2008.
(61) (a) Altomare, A.; Cascarano, G.; Giacovazzo, C.; Guagliardi, A.; Burla, M. C.; Polidori, G.; Camalli, M. *J. Appl. Crystallogr.* **1994**, *27*, 435−436. (b) Sheldrick, G. M. *SHELXL97—A Program for the Refinement of Crystal Structure*; University of Göttingen: Göttingen, Germany, 1997.
(62) Farrugia, L. J. *J. Appl. Crystallogr.* **1999**, *32*, 837−838.
(63) Brandenburg, K. *DIAMOND*, Version 3.1d; Crystal Impact GbR: Bonn, Germany, 2006.