RSC Advances

PAPER

View Article Online
View Journal | View Issue



Cite this: *RSC Adv.*, 2020, **10**, 44066

# Synthesis of novel star-shaped molecules based on a 1,3,5-triazine core linked to different heterocyclic systems as novel hybrid molecules†

Hadeer M. Diab, Mostafa E. Salem, Ismail A. Abdelhamid * and Ahmed H. M. Elwahy *

Received 23rd October 2020
Accepted 2nd December 2020

DOI: 10.1039/d0ra09025e

rsc.li/rsc-advances

The synthesis of novel star-shaped compounds based on an *s*-triazine core and linked to hexahydroacridinediones, pyrimido[4,5-*b*]quinolones, 1*H*-isoquinolino[2,1-*a*]quinolines, tetrahydro-4*H*-chromenes, dihydropyrano[2,3-*c*]pyrazoles, thiazole, or benzothiazole as new hybrid molecules through Michael and Hantzsch reactions is reported. For this purpose, 2,4,6-tris(4-formylphenoxy)benzaldehyde was used as a versatile precursor.



## Introduction

Star-shaped molecules have attracted considerable attention in recent decades because of their large application as promising compounds for use in optoelectronics and electrochromic devices[1–3] as well as in organic solar cells (OSCs).[4–6] They are also considered as building blocks for the creation of mesophases with interesting mesomorphic and photophysical properties.[7–9] Applications of star-shaped molecules as building units for dendrimers[10] as well as in supramolecular host-guest chemistry have also been reported.[11] In this regard, we recently reviewed the synthesis and application of star-shaped molecules.[12]

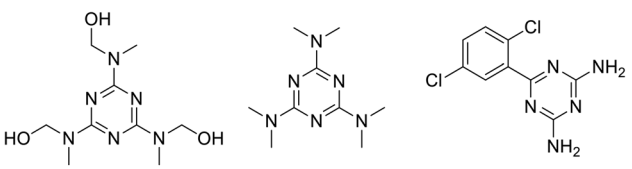
In particular, star-shaped molecules that contain 1,3,5-triazine as a central core have been found to play an important role as powerful chelating agents[13] and many of their derivatives have been employed in combinatorial and supramolecular chemistry.[14] The planarity of 1,3,5-triazine moiety and its symmetric nature plays a key role in self-organizing ability which enhances their use in the development of organic light-emitting diodes,[15,16] liquid crystalline materials,[6,17,18] dendrimers,[19,20] and nonlinear optical materials.[21–23] In addition, some *s*-triazine derivatives were reported as corrosion inhibitors for mild steel in 1 M HCl solution.[24] Moreover, some *s*-triazine derivatives have recently found extensive use as reagents in the conversion of functional groups.[25]

Moreover, *s*-triazine derivatives are an interesting class of compounds due to their diverse pharmacological activities as antibacterial,[26–28] antifungal,[29] antiviral,[30,31] antimalarials,[32,33] antiprotozoals,[34] anti-asthmatic activity,[35] estrogen receptor modulators,[36] cyclindependent kinase inhibitors.[37,38] In addition, the use of *s*-triazine derivatives as anticancer agents has also been extensively reported. In this regard, 1,3,5-triazine scaffold is present in some anticancer drugs, such as altretamine, trimelamol and irsogladine (Fig. 1).[39–42]

Furthermore, the development of hybrid molecules through the combination of different pharmacophores in one molecule may improve their biological efficacy and overcoming drug resistance.[43–45] In this aspect, heterocyclic hybrid skeleton comprising 1,3,5-triazine and different heterocyclic systems were found to exhibit modified therapeutic activities.[33,46–49] Synthetic chemistry is a highly creative discipline due to its ability to create new methodologies to contribute to the discovery of new drugs, and to enable the synthesis of important molecules with novel properties and functions in reasonable yields with a direct impact on the welfare of the world. Motivated by these findings and in conjunction with our ongoing research work on poly(heterocycles) as well as the new concept in drug design,[50–67] we report herein on the synthesis of novel hybrid molecules containing 1,3,5-triazine linked to different heterocyclic systems.

## Results and discussion

In general, the synthesis of star-shaped compounds bearing the *s*-triazine core was achieved starting from 2,4,6-trichloro-1,3,5-

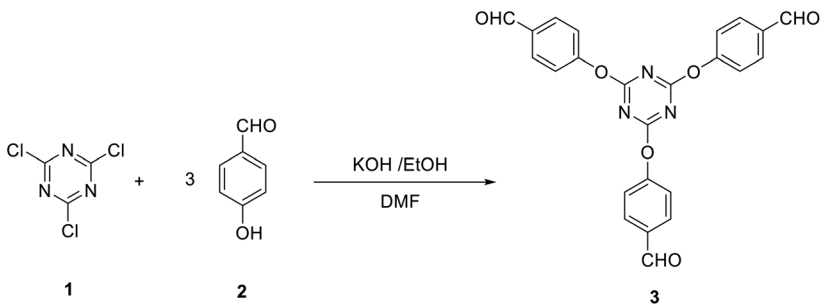



Trimelamol Altretamine Irsogladine

Fig. 1 Some anticancer drugs incorporating 1,3,5-triazine scaffold.

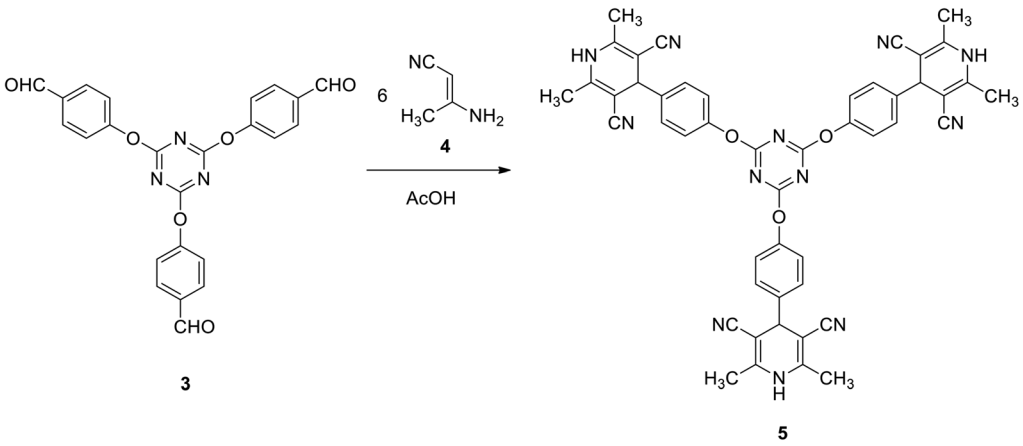
*Department of Chemistry, Faculty of Science, Cairo University, Giza 12613, Egypt. E-mail: ismail_shafy@yahoo.com; aelwahy@hotmail.com*

† Electronic supplementary information (ESI) available. See DOI: 10.1039/d0ra09025e




1 2 3

Scheme 1 Synthesis of tris-aldehyde **3**.

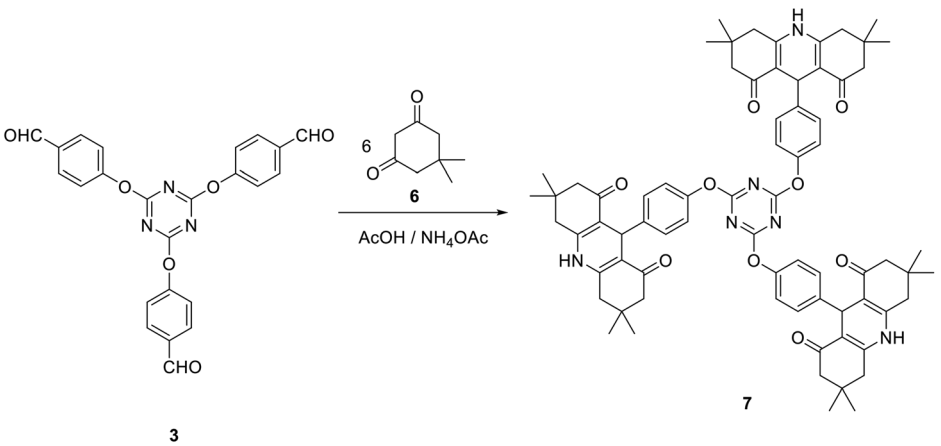



3 5

Scheme 2 Synthesis of tris(2,6-dimethyl-1,4-dihydropyridine-3,5-dicarbonitrile) **5**.

triazine due to the simple displacement of chlorine atoms by different nucleophiles. These reactions open access to many useful molecules of important applications in medicinal chemistry as well as in material science.[12] We utilized this strategy to synthesize 4,4′,4″-((1,3,5-triazine-2,4,6-triyl)tris(oxy)) tribenzaldehyde (**3**), by a modified procedure to some reported methods,[68–70] as a precursor for a variety of star-shaped compounds based on *s*-triazine. Thus, the reaction of three equivalents of potassium 4-formylphenolate (obtained upon treatment of *p*-hydroxybenzaldehyde **2** with KOH in ethanol) with one equivalent of 2,4,6-trichloro-1,3,5-triazine **1** in dimethylformamide at 0 °C afforded **3** in 82% yield (Scheme 1).

Firstly, we investigate the reactivity of tris(aldehyde) **3** towards the synthesis of tris(2,6-dimethyl-1,4-dihydropyridine-3,5-dicarbonitrile) **5** through reaction with 6 equivalents of 3-aminobut-2-enenitrile **4** in acetic acid under reflux. Compound **5** was successfully obtained in 88% yield (Scheme 2).




3 7

Scheme 3 Synthesis of tris(hexahydroacridine-1,8-diones) **7**.

The structure of compound **5** was confirmed spectroscopically, as the $^1$H NMR spectrum revealed a characteristic singlet integrated by 18H at $\delta$ 2.06 for the six methyl groups. It also showed a singlet signal at $\delta$ 4.47 for the pyridine-H. In addition, it exhibited a singlet signal characteristic for the NH group at $\delta$ 9.58. Furthermore, the $^{13}$C NMR spectrum of **5** was found to be in agreement with the proposed structure, it showed the methyl signal at $\delta$ 18.3 and the pyridine-C at $\delta$ 40.7.

Moreover, tris(hexahydroacridine-1,8-diones) **7** in which the acridinedione moiety is connected to 1,3,5-triazine core *via* ether linkage can also be obtained in good yield *via* multicomponent reaction of dimedone **6** with tris(aldehyde) **3** and ammonium acetate in acetic acid at reflux (Scheme 3).

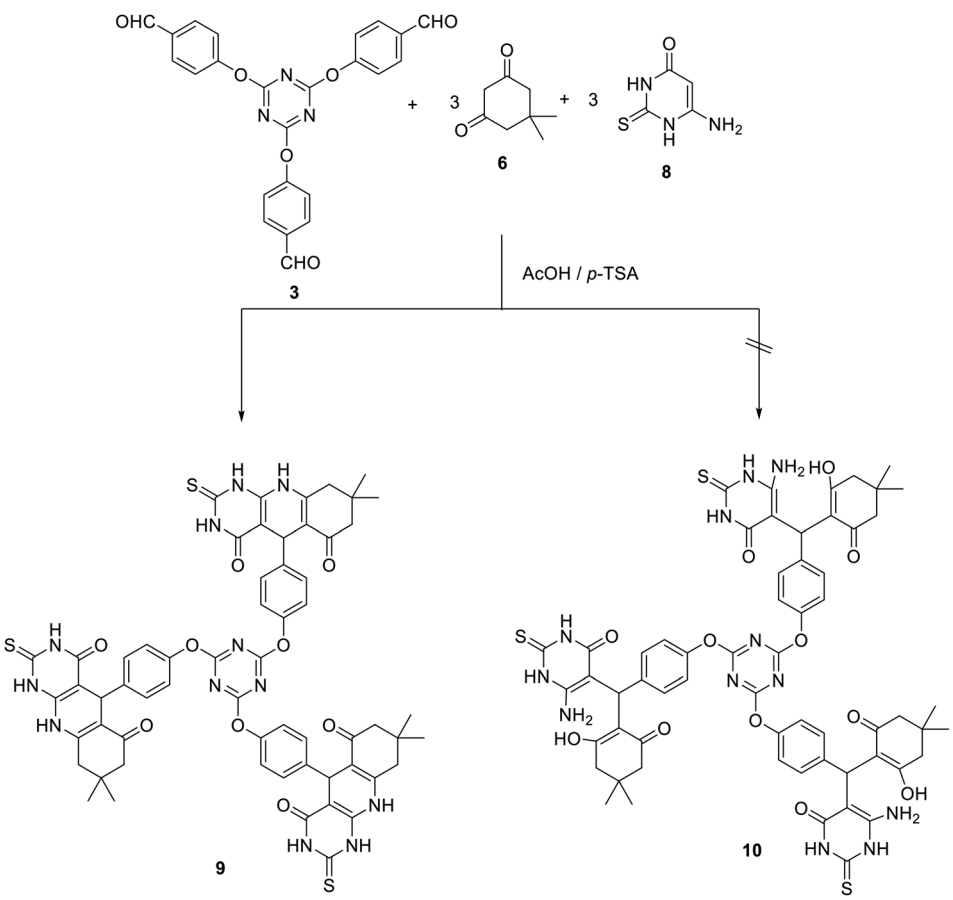
The IR spectra of compound **7** suggested the presence of NH group at 3277 cm$^{-1}$. In addition, the carbonyl group appeared at 1712 cm$^{-1}$. The $^1$H NMR spectrum of **7** suggested the existence of two singlets integrated by 36 protons at $\delta$ 0.87 and $\delta$ 1.01 allocated to twelve $CH_3$ groups. Moreover, the singlet signal at $\delta$ 4.70 is corresponding to H9. The NH group appeared as a broad singlet signal at $\delta$ 9.20. All other signals appeared at their expected positions. Moreover, the $^{13}$C NMR spectrum of **7** was found to be in accordance with the proposed structure, it showed the C9 at $\delta$ 32.1 and the carbonyl group at $\delta$ 194.8. All other carbon signals appeared at their expected positions.

Besides, the three-component Hantzsch-like reaction of tris(aldehyde) **3** with three equivalents of each of 6-aminouracil **8** and 5,5-dimethyl-1,3-cyclohexanedione **6** in acetic acid at reflux in the presence of *p*-TSA as a catalyst yielded the corresponding tris(pyrimido[4,5-*b*]quinolines) **9** in 72% yield. In this case, the uncyclized adduct **10** has not been obtained (Scheme 4).

The IR spectrum of compound **9** suggested the presence of NH groups at 3200 cm$^{-1}$. In addition, the carbonyl groups appeared around 1668 cm$^{-1}$. The $^1$H NMR spectrum of **9** suggested the existence of a singlet signal at $\delta$ 4.81 corresponding to H5. The NH group appeared as broad signals at $\delta$ 8.59, 11.89, and 12.01. All other signals appeared at their expected positions. Moreover, the $^{13}$C NMR spectrum of **9** showed the C5 at $\delta$ 40.2 and the carbonyl group at $\delta$ 173 and 194.4.

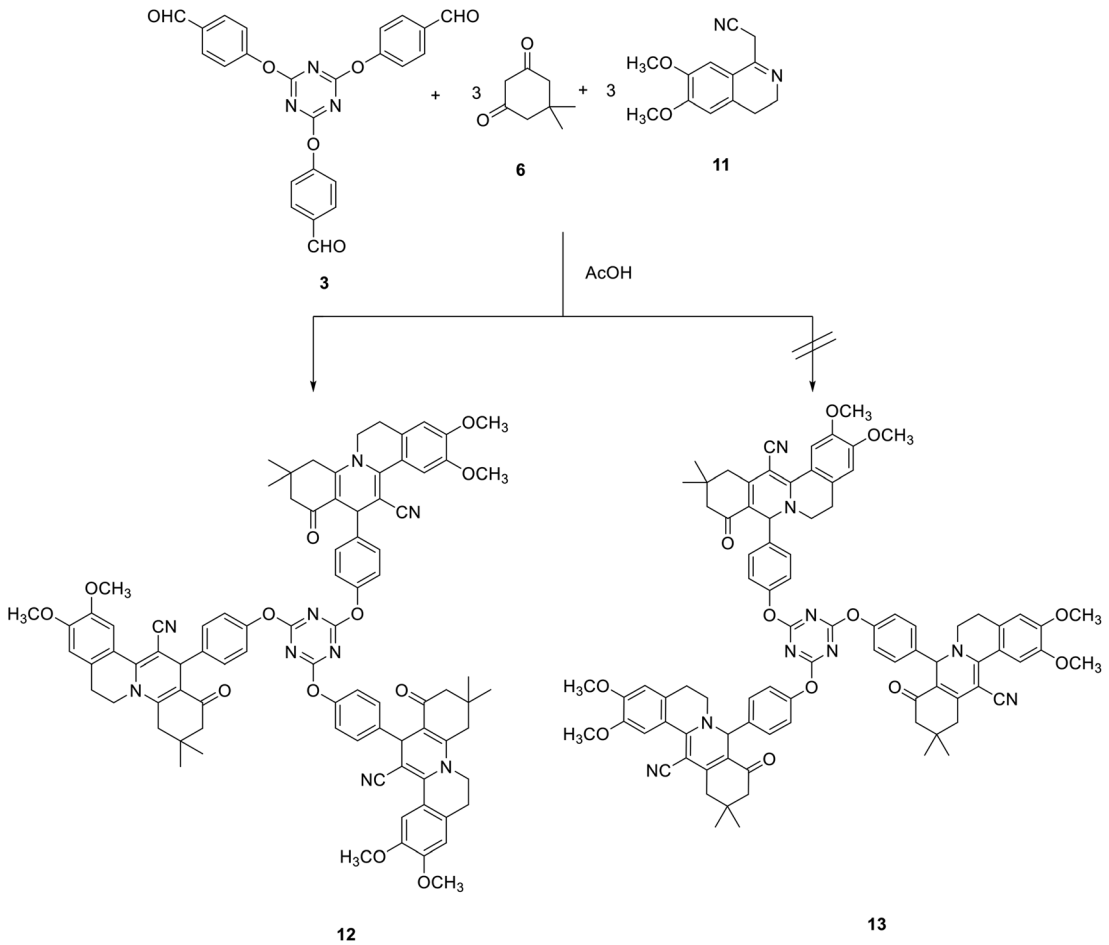
The synthesis of tris(1*H*-isoquinolino[2,1-*a*]quinoline-12-carbonitrile) **12** was also studied by the reaction of tris-aldehyde **3** with 2-(6,7-dimethoxy-3,4-dihydroisoquinolin-1-yl) acetonitrile **11**[71] and dimedone **6** in acetic acid at reflux. The cyclocondensation reaction can also lead to the formation of tris(5*H*-isoquinolino[3,2-*a*]isoquinoline-13-carbonitrile) **13** (Scheme 5).

The regioselectivity was approved on the basis of recent literature supporting the formation of 9,10-dimethoxy-13-(4-methoxyphenyl)-3,3-dimethyl-1-oxo-2,3,4,6,7,13-hexahydro-1*H*-isoquinolino[2,1-*a*]quinoline-12-carbonitrile **14** (Fig. 2) using X-




Scheme 4 Synthesis of tris(pyrimido[4,5-*b*]quinolines) **9**.




Scheme 5 Synthesis of tris(1*H*-isoquinolino[2,1-*a*]quinoline-12-carbonitrile) **12**.

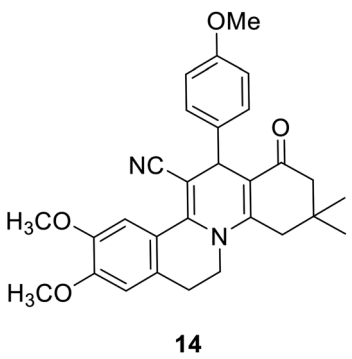



Fig. 2 Structure of hexahydro-1*H*-isoquinolino[2,1-*a*]quinoline-12-carbonitrile **14**.

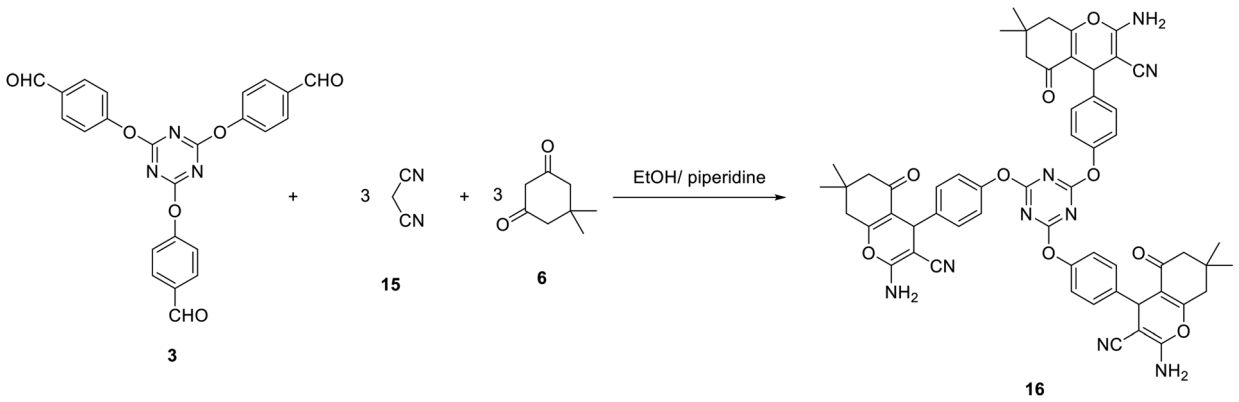
ray crystallography and 2D-HMBC spectroscopy *via* the Hantzsch-like reaction of 4-methoxybenzaldehyde with 2-(6,7-dimethoxy-3,4-dihydroisoquinolin-1-yl)acetonitrile and dimedone in the presence of acetic acid.[72]

The IR spectra of compound **12** indicated the presence of the cyano group at 2188 $cm^{-1}$ and the carbonyl group as a broad band at 1629 $cm^{-1}$. The $^1H$ NMR spectra of **12** revealed a characteristic singlet signal at $\delta$ 4.71 for H-13. In addition, the $^{13}C$ NMR spectrum of compound **12** featured the pyridine-C13 at 37.7 ppm.

Our study was expanded to include the use of Michael addition reactions as an effective method for the synthesis of novel tris(2-amino-7,7-dimethyl-5-oxo-5,6,7,8-tetrahydro-4*H*-chromene-3-carbonitrile) **16**. Thus, compound **16** was successfully obtained by a multicomponent reaction of one equivalent of tris-aldehydes **3** with three equivalents of both malononitrile **15** and dimedone **6** in EtOH/piperidine (Scheme 6).

The constitution of compound **16** was spectroscopically determined based on the basis of elemental analysis and spectral data. The IR spectra of compound **16** indicated the presence of amino group at 3365 and 3313 $cm^{-1}$. In addition, it revealed the cyano group at 2190 $cm^{-1}$. The carbonyl group appeared as a broad band at 1684 $cm^{-1}$. The $^1H$-NMR spectrum of **16** suggested the existence of two singlets integrated by 18 protons at $\delta$ 0.94 and $\delta$ 1.04 assigned to six $CH_3$. In addition, it revealed the pyran-H4 as a singlet signal at $\delta$ 4.22 ppm.

Likewise, we have also successfully demonstrated the synthesis of tris(6-amino-3-methyl-1,4-dihydropyrano[2,3-*c*]pyrazole-5-carbonitrile) **19** and tris(benzene-4,1-diyl)tris(2-amino-5-oxo-4,5-dihydropyrano[3,2-*c*]chromene-3-carbonitrile) **20** in 73 and 82% yields by a three-component reaction of one

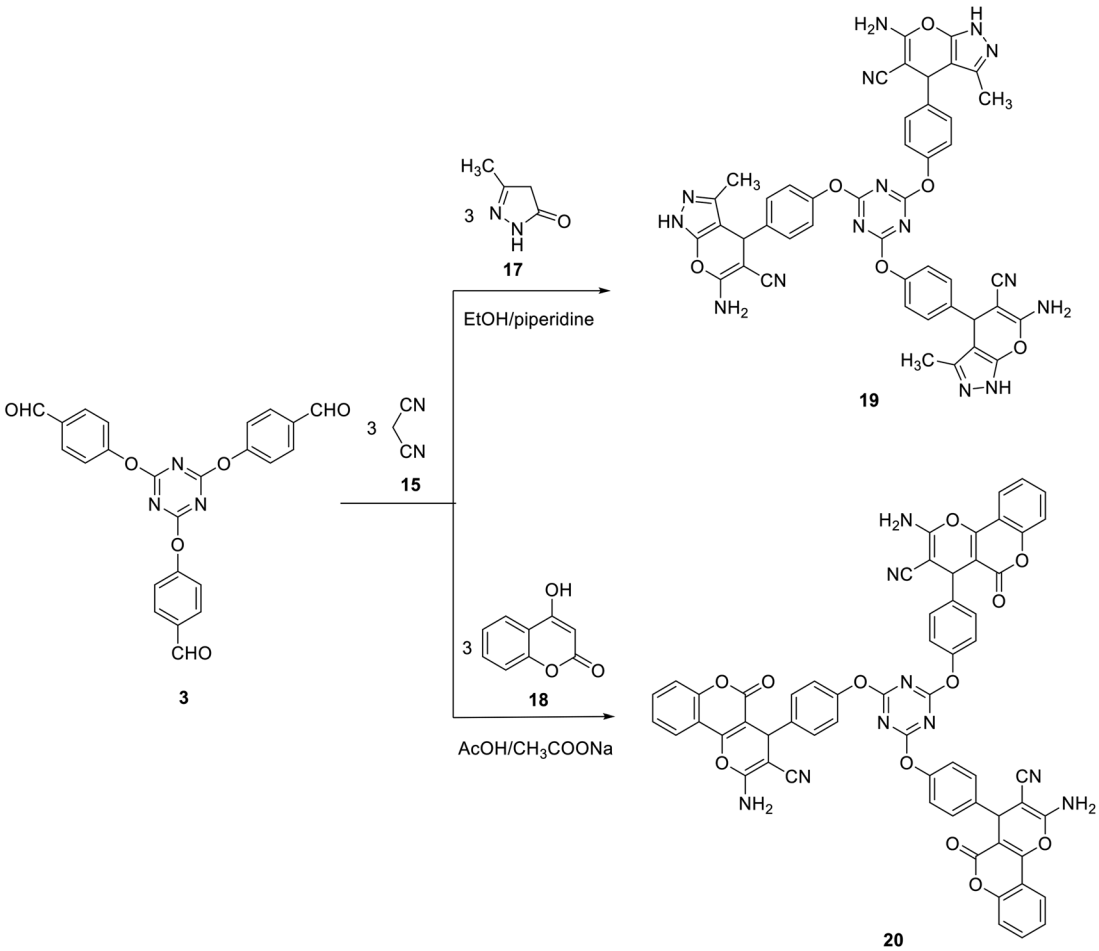



Scheme 6 Synthesis of tris(5,6,7,8-tetrahydro-4*H*-chromene-3-carbonitrile) **16**.

mole of tris-aldehyde **3** with three moles of both of malononitrile **15** and pyrazolone **17** (in ethanol in the presence of catalytic amount piperidine) or 4-hydroxycoumarin **18** (in the presence of acetic acid/sodium acetate) (Scheme 7).

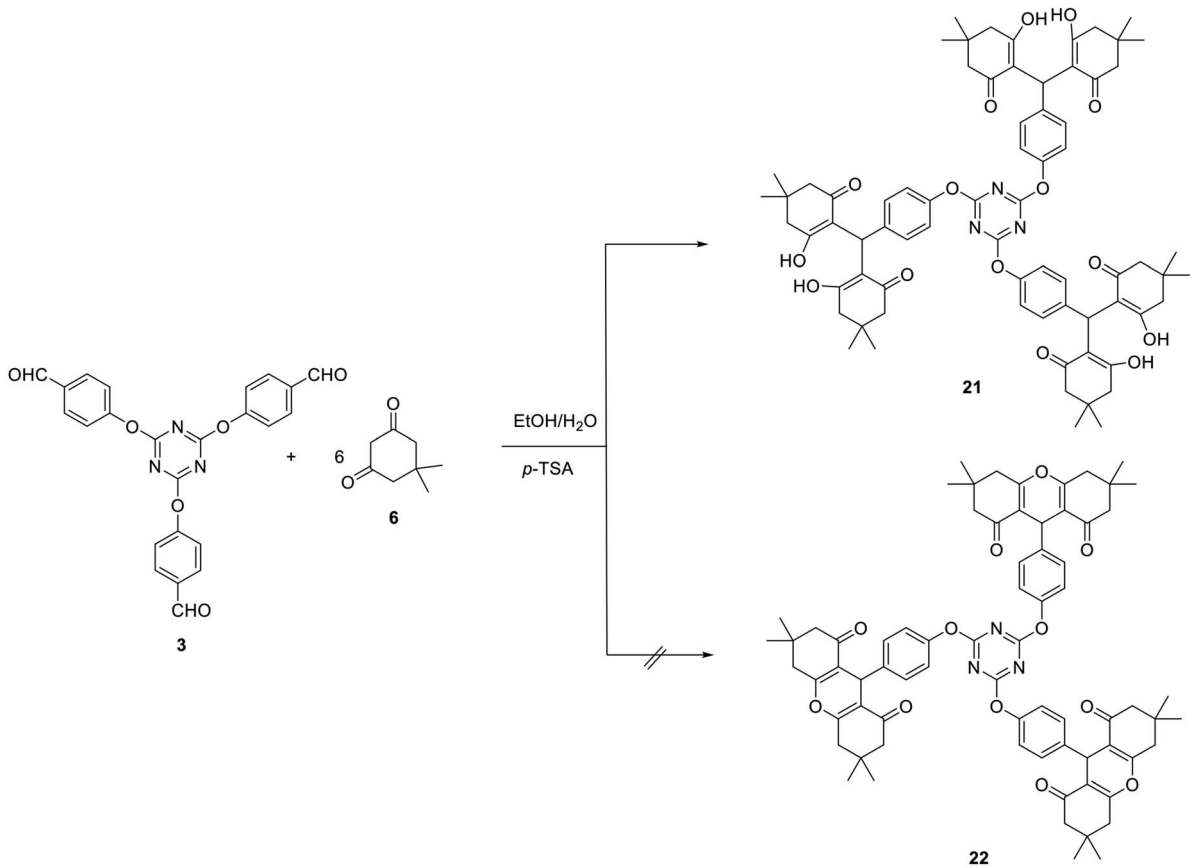
The structure of compound **19** was confirmed by their elemental analysis and spectral results. Thus, IR spectrum of compound **19** indicated the presence of amino group at $\nu$ 3295 and 3168 $cm^{-1}$ and a cyano group at $\nu$ 2187 $cm^{-1}$. The $^1H$ NMR spectrum indicated the presence of the pyran-H4 and the pyrazole methyl protons as two singlet signals at $\delta$ 4.64 and $\delta$ 1.78, respectively.

The infrared spectra of compound **20** indicated the presence of amino group at $\nu$ 3255 and 3184 $cm^{-1}$. In addition, it revealed the cyano band at $\nu$ 2197 $cm^{-1}$. The carbonyl group appeared as a broad band at $\nu$ 1715 $cm^{-1}$. The $^1H$ NMR spectrum of **20** indicated the presence of the pyran-H4 as a singlet signal at $\delta$ 4.49.

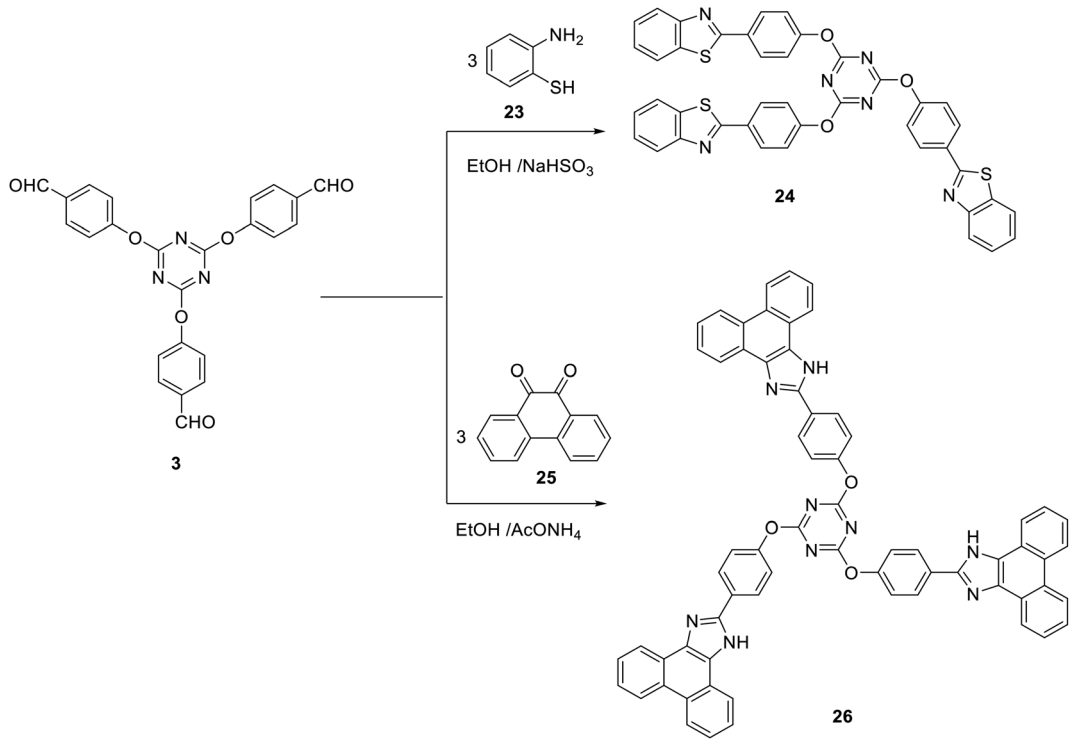



Scheme 7 Synthesis of tris(dihydropyrano[2,3-*c*]pyrazole-5-carbonitrile) **19** and tris(dihydropyrano[3,2-*c*]chromene-3-carbonitrile) **20**.




Scheme 8 Synthesis of tris(tetraketone) **21**.




Scheme 9 Synthesis of tris(benzothiazole) **24** and tris(1*H*-phenanthro[9,10-*d*] imidazole) **25**.

The utility of tris-aldehyde **3** as a building block for novel tris(hexahydro-1*H*-xanthene-1,8(2*H*)-dione) **22** has also been attempted. Unfortunately, the reaction of one equivalent of **3** with six equivalents of dimedone (**6**) in the presence of 15 mol% of *p*-TSA in a mixture of ethanol/$H_2O$ (2 : 1) or DCE as solvents did not lead to the formation of **22** and instead the interesting tris(tetraketone) **21** was obtained in 83% yield (Scheme 8).

Tetraketone derivatives are considered not only as an important class of biologically active compounds but also as significant precursors for the synthesis of various fused heterocyclic.[73]

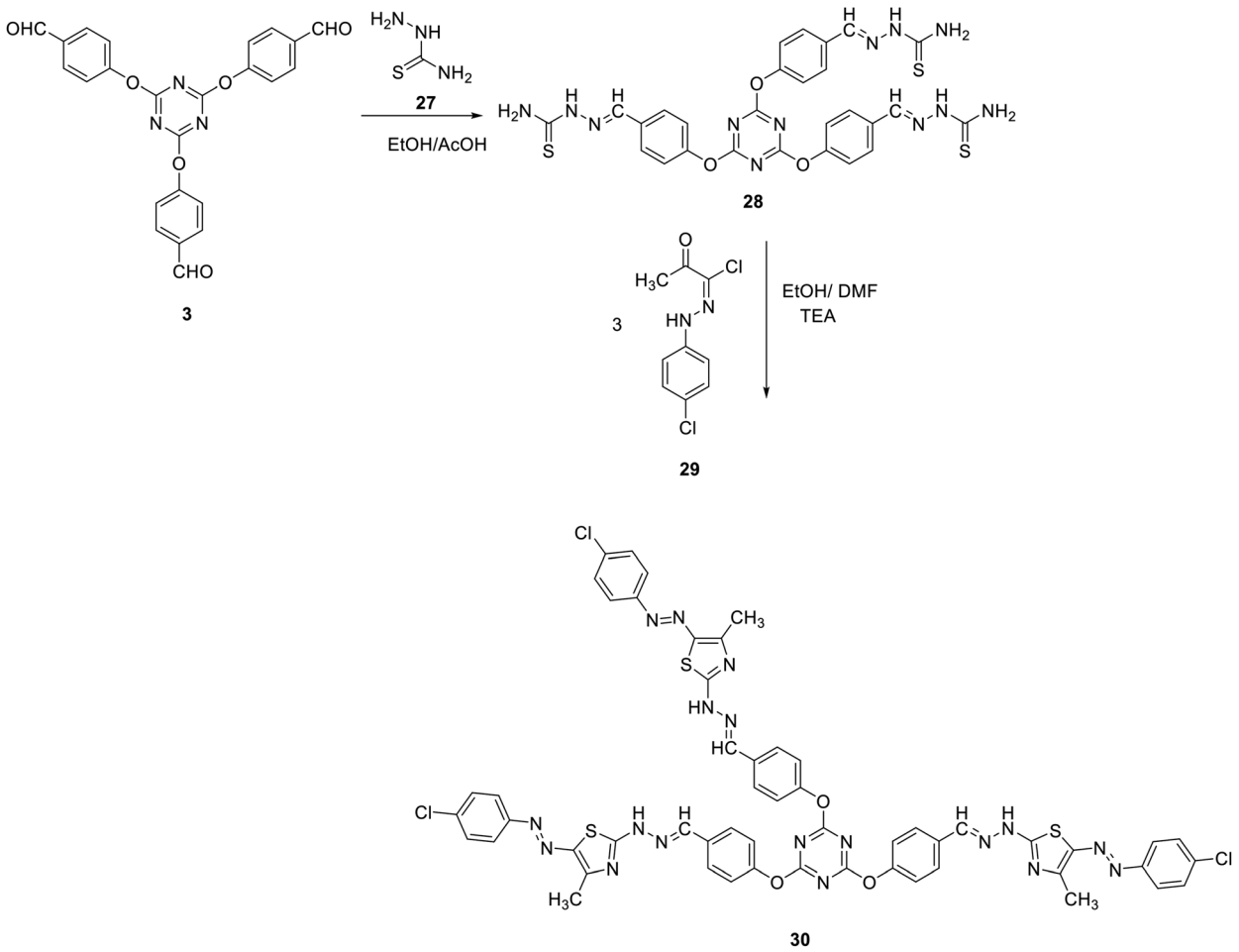
The structure of compound **21** was spectroscopically verified. In the IR spectrum, the carbonyl and the hydroxyl stretching frequencies were noticed at 1650 and 3345 $cm^{-1}$, respectively. The $^1H$ NMR spectrum of **21** displayed a broad signal at $\delta$ 9.20 characteristic for the OH protons in addition to the methine-H at $\delta$ 4.42.

Subjecting the tris(aldehyde) **3** to the cyclocondensation reaction with 2-aminothiophenol **23** in ethanol at reflux in the presence of $NaHSO_3$ afforded the tris(benzothiazole) **24** in 61% yield (Scheme 9). Moreover, the three-component cyclocondensation reaction of tris-aldehyde **3** with 9,10-phenanthrenequinone **25** and ammonium acetate afforded the corresponding tris(1*H*-phenanthro[9,10-*d*]imidazole) **26** as a new building block for blue light-emitting materials (Scheme 9).[74]

Compound **24** was confirmed by the absence of characteristic absorption bands or signals for CHO, $NH_2$, or SH in its IR or $^1H$ NMR spectra. The structure of the tris(imidazole) **26** was defined on the basis of spectral data. Thus, its IR spectra indicated the absence of a peak characteristic for a carbonyl group. In addition, it revealed the absorption of the NH group at 3305 $cm^{-1}$. The $^1H$ NMR spectrum of **26** indicated the presence of a singlet signal integrated by three protons at $\delta$ 13.47 assigned to the NH protons.

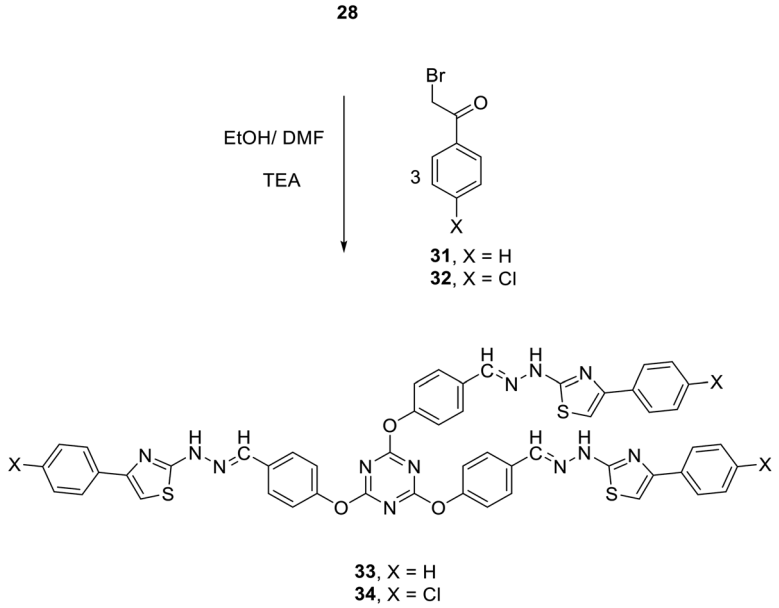
The synthetic utility of tris-aldehyde **3** as building blocks for novel tris(thiazoles) through Hantzsch thiazole synthesis was also investigated. Thus, the tris(aldehyde thiosemicarbazone) **28** was first synthesized in 90% yield, by acid-catalyzed condensation of thiosemicarbazide **27** with tris(aldehyde) **3**.[75] Reaction of **28** with the corresponding *N*-(4-chlorophenyl)-2-oxopropanehydrazonoyl chloride **29** in refluxing ethanol/DMF in the presence of TEA as a catalyst gave the corresponding tris(arydiazenyl)thiazole **30** in 85% yield (Scheme 10).

The structure of compound **30** has been verified by spectral as well as elemental analyses. The IR spectra of **30** as a representative example showed an absorption band at 3424 $cm^{-1}$ due to the NH group. Moreover, its $^1H$ NMR spectrum showed




Scheme 10 Synthesis of tris(arydiazenyl)thiazole **30**.

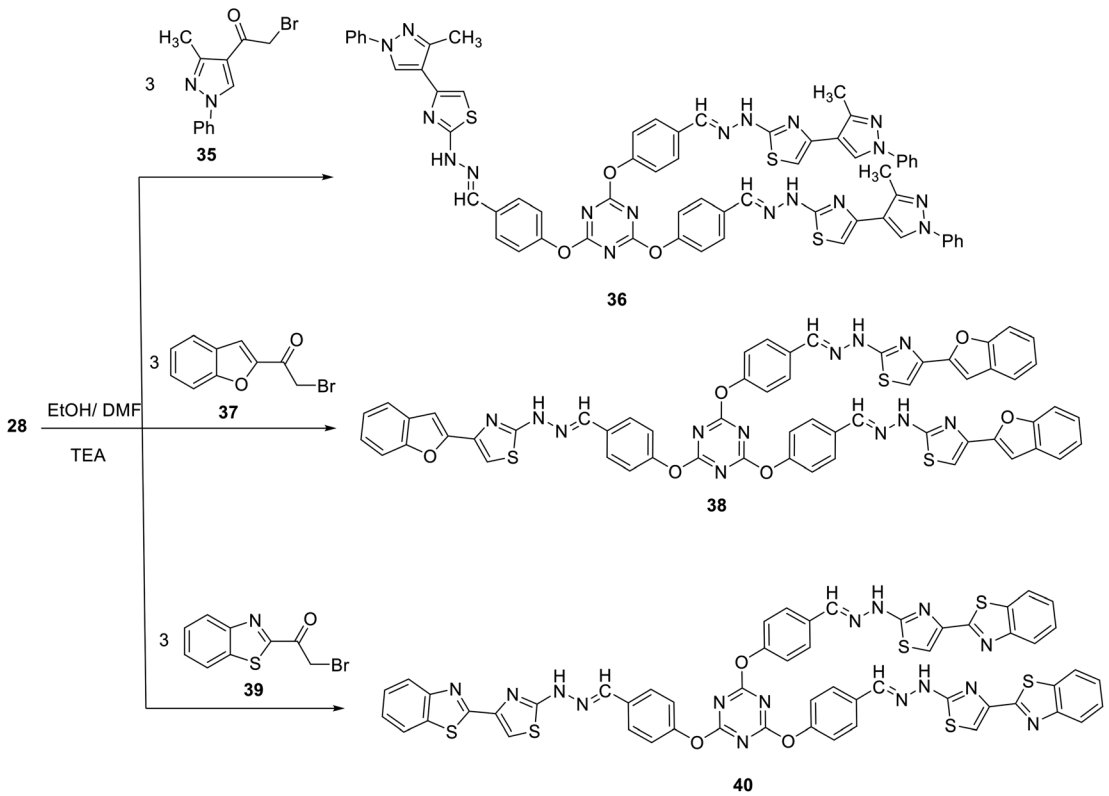



Scheme 11 Synthesis of 2,4,6-tris(4-arylthiazol-2 ylhydrazonomethylphenoxy)-1,3,5-triazines **33** and **34**.

a $D_2O$-exchangeable signal at $\delta$ 10.53 due to NH protons together with sharp singlet signals at $\delta$ 2.56 and $\delta$ 8.61 attributed to the 4-$CH_3$ of thiazole group and the methine protons (N=CH), respectively. All other protons appeared at the predicted chemical shifts and integral values.

Furthermore, the reaction of **28** with three equivalents of each of 2-bromo-1-phenylethanone **31** and 2-bromo-1-(4-chlorophenyl)ethanone **32** in ethanol at reflux in the presence of few drops of TEA afforded 2,4,6-tris(4-(-(2-(4-arylthiazol-2-yl) hydrazono)methyl)phenoxy)-1,3,5-triazines **33** and **34** in 79 and 81% yields, respectively (Scheme 11).

In analogy, reaction of compound **28** with 2-bromo-1-(5-methyl-1-phenyl-1*H*-pyrazol-4-yl)ethanone **35** in ethanol at reflux in the presence of few drops of TEA afforded 2,4,6-tris(4-




Scheme 12 Synthesis of tris(thiazoles) **36**, **38** and **40**.

(-(2-(4-(3-methyl-1-phenyl-1*H*-pyrazol-4-yl)thiazol-2yl) hydrazono)methyl)phenoxy)-1,3,5-triazine **36** in 66% yield (Scheme 12). Compound **35** was synthesized by the reaction of phenylhydrazine with ((dimethyl-amino) methylene)pentane-2,4-dione, obtained upon treatment of acetylacetone with dimethylformamide dimethylacetal (DMF/DMA), followed by bromination through treatment with $Br_2$ in AcOH.[52,76]

In an attempt to construct novel tris(thiazole) linked to other heterocylic moieties aiming at achieving the concept of molecular hybridization, we studied the synthesis of novel 2,4,6-tris(4-(-(2-(4-(benzofuran-2-yl)thiazol-2-yl)hydrazono)-methyl) phenoxy)-1,3,5-triazine **38** and 2,4,6-tris(4-(-(2-(4-(benzo[*d*]thiazol-2-yl) thiazol-2-yl)hydrazono)methyl)phenoxy)-1,3,5-triazine **40** using a similar strategy. Thus, reaction of tris(thiosemicarbazone) **28** with each of 1-(benzofuran-2-yl)-2-bromoethanone **37** and 1-(benzo[*d*]thiazol-2-yl)-2-bromoethanone **39** in ethanol at reflux in the presence of TEA afforded **38** and **40** in 62 and 76% yields, respectively (Scheme 12).

The structures of the newly synthesized compounds have been confirmed by spectral data as well as elementary analyses. The IR spectrum of tris(pyrazole) **36** as a representative example of this class of compounds showed an absorption band at 3427 $cm^{-1}$ because of (NH) together with the absence of absorption band characteristic for C=S group.[77] The symmetry of compound **36** is represented by a characteristic set of signals within its $^1H$ NMR spectrum. It revealed the presence of a $D_2O$-exchangeable singlet signal at $\delta$ 12.18 attributable to NH protons, a singlet signal at $\delta$ 6.84 attributed to C-5 protons of the thiazole rings, and a singlet signal at $\delta$ 8.03 because of methine protons (N=CH). All other protons were observed at the predicted chemical shifts and integral values.

# Conclusions

The most popular strategy in drug design as well as in the construction of important molecules is the synthesis of analogs of existing active molecules. The aim of this work was to develop new methodologies to tackle synthetic problems encountered in the synthesis of star-shaped molecules that contain 1,3,5-triazine as a central core with improved pharmacological and photophysical properties. In this respect, a simple protocol for the preparation of some star-shaped compounds based on *s*-triazine core linked to hexahydroacridinediones, pyrimido[4,5-*b*]quinolones, 1*H*-isoquinolino[2,1-*a*] quinolines, tetrahydro-4*H*-chromenes, dihydropyrano[2,3-*c*]pyrazoles, thiazole, or benzothiazole was developed. Hantzch and Michael reactions have been used as effective strategies for the synthesis of the target compounds from easily accessible precursors under mild reaction conditions. Moreover, multicomponent reactions (MCRs), which are associated with a range of advantages such as procedural efficiency, shorter reaction times, energy savings, and lower costs and time-consuming, were successfully used in this manuscript to synthesize the target compounds. The combination of two fused heterocyclic cores in a single molecular structure is supposed to take advantage of the pharmacological and physical properties of the resulting ligands. The successful synthesis of these compounds should open an access to a variety of star shaped molecules with interesting applications. Further analysis is underway to investigate the biological activities of the novel compounds. We believe also that some of the new star-shaped molecules should exhibit useful NLO properties on account of preliminary theoretical calculation of their polarizability and hyperpolarizability parameters. The theoretical as well as the experimental investigations are still underway and will be published separately because of the large quantity of data accumulated.

# Experimental

### General

Melting points were determined in open glass capillaries with a Gallenkamp apparatus. The infrared spectra were recorded in potassium bromide disks on a Pye Unicam SP 3-300 and Shimadzu FTIR 8101 PC infrared spectrophotometer. NMR spectra were recorded with a Varian Mercury VXR-300 NMR spectrometer operating at (300 MHz and 75 MHz) or Bruker AVS NMR spectrometer at (400 MHz and 101 MHz), respectively, using TMS as an internal standard. Chemical shifts were reported as $\delta$ values in ppm. Mass spectra (EI) were obtained at 70 eV with a type Shimadzu GCMQP 1000 EX spectrometer. Analytical thin-layer chromatography was performed using pre-coated silica gel 60 778 plates (Fluka), and the spots were visualized with UV light at 254 nm. Elemental analyses were performed on a Perkin-Elmer 240 micoanalyser at the Micro analytical Center of Cairo University. All chemicals were purchased from Sigma-Aldrich and used without further purification.

### Synthesis of 4,4′,4″-((1,3,5-triazine-2,4,6-triyl)tris(oxy)) tribenzaldehyde (3)

A solution of *p*-hydroxybenzaldehyde (3 mmol) and KOH (3 mmol) in ethanol (10 ml) was stirred for 10 min at room temperature. The solvent was then removed in *vacuo* and the remaining potassium salt was collected, dissolved in DMF (5 ml), and stirred for 10 min at 0 °C. A solution of the latter salt and 2,4,6-trichloro-1,3,5-triazine (1 mmol) in DMF (5 ml) was allowed to stir for 15 min at 0 °C during which time KBr was precipitated. The solvent was then removed in *vacuo* and the remaining material was washed with water (20 ml), collected and crystallized from $H_2O$/EtOH (3 : 1) to give **3** as a colorless powder; yield: 82%; mp 170–175 °C. IR (KBr) $\nu$ 2839, 2746, 1705 $cm^{-1}$; $^1H$ NMR (300 MHz, DMSO-$d_6$) $\delta$ 7.46–7.49 (d, *J* 8.4 Hz, 6H, Ar–H), 7.95–7.98 (d, *J* 8.1 Hz, 6H, Ar–H), 9.98 (s, 3H, 3CHO). $^{13}C$ NMR (100 MHz, DMSO-$d_6$) $\delta$ 122.2, 131.1, 134.1, 155, 172.6, 191.8 ppm. MS (EI, 70 eV): *m*/*z* (%) 441 [$M^+$]. Anal. calcd for $C_{24}H_{15}N_3O_6$: C, 65.31; H, 3.43; N, 9.52. Found: C, 65.02; H, 3.29; N, 9.34.

### 4,4′,4″-(((1,3,5-Triazine-2,4,6-triyl)tris(oxy))tris(benzene-4,1-diyl))tris(2,6-dimethyl-1,4-dihydropyridine-3,5-dicarbonitrile) (5)

To a warm solution of tris-aldehyde **3** (1 mmol) in glacial acetic acid (5 ml) was added 3-aminocrotononitrile **4** (6 mmol). The resulting solution was heated at reflux for 1 h. The solid obtained was collected and crystalized from DMF EtOH to give **5** as pale yellow crystals; yield: 88%; mp > 300 °C. IR (KBr) $\nu$ 3317

(NH), 2198 (CN) $cm^{-1}$; $^1H$ NMR (400 MHz, DMSO-$d_6$) $\delta$ 02.06 (s, 18H, $6CH_3$), 4.47 (s, 3H, 3CH), 7.29–7.36 (m, 12H, Ar–H), 9.58 (s, 3H, 3NH). $^{13}C$ NMR (100 MHz, DMSO-$d_6$) $\delta$ 18.3, 40.7, 82.9, 119.8, 122.4, 129.2, 142.2, 147.5, 151.1, 173.5. MS (EI, 70 eV): *m*/*z* (%) 828 [$M^+$]. Anal. calcd for $C_{48}H_{36}N_{12}O_3$: C, 69.55; H, 4.38; N, 20.28. Found: C, 69.27; H, 4.11; N, 20.02.

### 9,9′,9″-(((1,3,5-Triazine-2,4,6-triyl)tris(oxy))tris(benzene-4,1-diyl))tris(3,3,6,6-tetramethyl-3,4,6,7,9,10-hexahydroacridine-1,8(2*H*,5*H*)-dione) (7)

A mixture of tris-aldehyde **3** (1 mmol), dimedone **6** (6 mmol) and ammonium acetate (5 mmol) in glacial acetic acid (3 ml) was heated at reflux for 6 h. The obtained crude solid was collected and crystalized from DMF/EtOH to give **7** as yellow crystals; yield: 83%; mp > 300 °C. IR (KBr) $\nu$ 3277 (NH), 1712 (C=O) $cm^{-1}$; $^1H$ NMR (400 MHz, DMSO-$d_6$) $\delta$ 0.87 (s, 18H, $6CH_3$), 1.01 (s, 18H, $6CH_3$), 2.00–2.18 (m, 12H, 6 $CH_2$), 2.32–2.49 (m, 12H, $6CH_2$), 4.70 (s, 3H, 3CH), 6.51–6.53 (d, *J* 8.4 Hz, 6H, Ar–H), 6.91–6.94 (d, *J* 8.4 Hz, 6H, Ar–H), 9.20 (s, 3H, 3NH). $^{13}C$ NMR (100 MHz, DMSO-$d_6$) $\delta$ 26.9, 29.6, 32.1, 32.6, 50.8, 112.3, 114.8, 128.9, 138.4, 149.3, 155.5, 172.5, 194.8. MS (EI, 70 eV): *m*/*z* (%) 1170 [$M^+$]. Anal. calcd for $C_{72}H_{78}N_6O_9$: C, 73.82; H, 6.71; N, 7.17. Found: C, 73.66; H, 6.49; N, 7.03.

### 5,5′,5″-(((1,3,5-Triazine-2,4,6-triyl)tris(oxy))tris(benzene-4,1-diyl))tris(8,8 dimethyl-2-thioxo-2,3,5,8,9,10-hexahydropyrimido[4,5-*b*]quinoline-4,6(1*H*,7*H*)-dione) (9)

A mixture of tris-aldehyde **3** (1 mmol), dimedone **6** (3 mmol) and 6-aminothiouracil **8** (3 mmol) in glacial acetic acid (3 ml) was heated at reflux for 3 h. The solid formed was collected and crystalized from DMF to give **9** as creamy powder; yield: 72%; mp > 300 °C. IR (KBr) $\nu$ 3200 (NH), 1668 (C=O) $cm^{-1}$; $^1H$ NMR (300 MHz, DMSO-$d_6$) $\delta$ 0.92 (s, 9H, $3CH_3$), 1.01 (s, 9H, $3CH_3$), 2.06–2.22 (m, 6H, $3CH_2$), 2.45–2.48 (m, 6H, $3CH_2$), 4.81 (s, 3H, 3CH), 7.05–7.08 (d, *J* 8.4 Hz, 6H, Ar–H), 7.22–7.25 (d, *J* 8.4 Hz, 6H, Ar–H), 8.59 (br, 3H, 3NH), 11.89 (br, 3H, 3NH), 12.01 (br, 3H, 3NH). $^{13}C$ NMR (75 MHz, DMSO-$d_6$) $\delta$ 26.9, 28.6, 32.3, 32.6, 40.2, 50.1, 94, 110.7, 120.8, 128.6, 143.6, 144.2, 149.5, 160.8, 173, 194.4. MS (EI, 70 eV): *m*/*z* (%) 1182 [$M^+$]. Anal. calcd for $C_{60}H_{54}N_{12}O_9S_3$: C, 60.90; H, 4.60; N, 14.20. Found: C, 60.84; H, 4.33; N, 14.03.

### 13,13′,13″-(((1,3,5-Triazine-2,4,6-triyl)tris(oxy))tris(benzene-4,1-diyl))tris(9,10-dimethoxy-3,3-dimethyl-1-oxo-2,3,4,6,7,13-hexahydro-1*H*-isoquinolino[2,1-*a*] quinoline-12-carbonitrile) (12)

A mixture of tris-aldehyde **3** (1 mmol), dimedone **6** (3 mmol) and 2-(6,7-dimethoxy-3,4-dihydroisoquinolin-1-yl)acetonitrile **11** (3 mmol) in glacial acetic acid (3 ml) was heated at reflux for 6 h. The formed crude solid was collected, washed with ethanol and crystalized from DMF to give **12** as yellow crystals; yield: 77%; mp 260–262 °C; (DMF). IR (KBr) $\nu$ 2188 (C≡N), 1629 (C=O) $cm^{-1}$; $^1H$ NMR (400 MHz, DMSO-$d_6$) $\delta$ 0.99 (s, 9H, $3CH_3$), 1.02 (s, 9H, $3CH_3$), 2.18 (m, 6H, $3CH_2$), 2.50 (m, 6H, $3CH_2$), 2.83–2.91 (m, 6H, $CH_2$), 3.51–3.57 (m, 3H, $CH_2$), 3.75 (s, 9H, $3OCH_3$), 3.82 (s, 9H, $3OCH_3$), 3.89–3.92 (m, 3H, $CH_2$), 4.71 (s, 3H, pyridine-H13), 7.02 (s, 3H, Ar–H), 7.14–7.31 (m, 12H, Ar–H), 7.66 (s, 3H, Ar–H). $^{13}C$ NMR (100 MHz, DMSO-$d_6$) $\delta$ 28.2, 28.7, 28.8, 32.7, 37.4, 43.6, 49.8, 56.1, 56.2, 84.9, 110.4, 110.9, 111.2, 114.3, 120.2, 122.1, 128.5, 131.3, 142.4, 147.2, 151.0, 152.3, 158.6, 172.5, 195.1. MS (EI, 70 eV): *m*/*z* (%) 1443 [$M^+$]. Anal. calcd for $C_{87}H_{81}N_9O_{12}$: C, 72.33; H, 5.65; N, 8.73. Found: C, 72.07; H, 5.49; N, 8.62.

### 4,4′,4″-(((1,3,5-Triazine-2,4,6-triyl)tris(oxy))tris(benzene-4,1-diyl))tris(2-amino-7,7-dimethyl-5-oxo-5,6,7,8-tetrahydro-4*H*-chromene-3-carbonitrile) (16)

To a mixture of tris-aldehyde **3** (1 mmol), malononitrile **15** (3 mmol) and dimedone **6** (3 mmol) in absolute ethanol (4 ml), piperidine (0.2 ml) was added. The reaction mixture was heated at reflux for 3 h. The crude solid formed was collected and crystalized from DMF/EtOH to give **16** as buff powder; yield: 88%; mp 285–290 °C. IR (KBr) $\nu$ 3365, 3313 ($NH_2$), 2190 (C≡N), 1684 (C=O) $cm^{-1}$; $^1H$ NMR (400 MHz, DMSO-$d_6$) $\delta$ 0.94 (s, 9H, $3CH_3$), 1.04 (s, 9H, $3CH_3$), 2.10–2.14 (m, 6H, $3CH_2$), 2.24–2.51 (m, 6H, $3CH_2$), 4.22 (s, 3H, 3CH), 7.02 (br, 6H, $3NH_2$), 7.11–7.13 (d, *J* 8.4 Hz, 6H, Ar–H), 7.17–7.19 (d, *J* 8.4 Hz, 6H, Ar–H). $^{13}C$ NMR (100 MHz, DMSO-$d_6$) $\delta$ 27.2, 28.9, 32.3, 35.5, 50.4, 58.6, 113.2, 120.1, 122.0, 128.5, 142.3, 150.8, 159, 162.8, 165.9, 172.3, 196.1. MS (EI, 70 eV): *m*/*z* (%) 1005 [$M^+$]. Anal. calcd for $C_{57}H_{51}N_9O_9$: C, 68.05; H, 5.11; N, 12.53. Found: C, 67.76; H, 5.03; N, 12.24.

### 4,4′,4″-(((1,3,5-Triazine-2,4,6-triyl)tris(oxy))tris(benzene-4,1-diyl))tris(6-amino-3-methyl-1,4-dihydropyrano[2,3-*c*]pyrazole-5-carbonitrile) (19)

To a mixture of tris-aldehyde **3** (1 mmol), malononitrile **15** (3 mmol) and pyrazolone **17** (3 mmol) in absolute ethanol (4 ml), piperidine (0.2 ml) was added. The reaction mixture was heated at reflux for 3 h. The crude solid formed was collected and crystalized from EtOH to give **19** as creamy powder; yield: 73%; mp 246–250 °C; (EtOH). IR (KBr) $\nu$ 3453 (NH), 3295, 3168 ($NH_2$), 2187 (C≡N) $cm^{-1}$; $^1H$ NMR (300 MHz, DMSO-$d_6$) $\delta$ 1.78 (s, 9H, $3CH_3$), 4.64 (s, 3H, 3CH), 6.85 (s, 6H, $3NH_2$), 7.12–7.15 (d, *J* 8.7 Hz, 6H, Ar–H), 7.19–7.21 (d, *J* 8.4 Hz, 6H, Ar–H), 12.08 (s, 3H, 3NH). $^{13}C$ NMR (75 MHz, DMSO-$d_6$) $\delta$ 9.6, 35.6, 57.1, 97.6, 120.7, 121.7, 128.4, 135.6, 141.5, 150.5, 154.7, 160.8, 172. MS (EI, 70 eV): *m*/*z* (%) 879 [$M^+$]. Anal. calcd for $C_{45}H_{33}N_{15}O_6$: C, 61.43; H, 3.78; N, 23.88. Found: C, 61.22; H, 3.59; N, 23.65.

### 4,4′,4″-(((1,3,5-Triazine-2,4,6-triyl)tris(oxy))tris(benzene-4,1-diyl))tris(2-amino-5-oxo-4*H*,5*H*-pyrano[3,2-*c*]chromene-3-carbonitrile) (20)

A mixture of tris-aldehyde **3** (1 mmol), malononitrile **15** (3 mmol), 4-hydroxycoumarin **18** (3 mmol) and sodium acetate (3 mmol) in glacial acetic acid (3 ml) was heated at reflux for 3 h. The crude solid formed was collected and crystalized from DMF/EtOH to give **20** as grey powder; yield: 82%; mp 255–265 °C; (DMF/EtOH). IR (KBr) $\nu$ 3323, 3184 ($NH_2$), 2197 (C≡N), 1715 (C=O) $cm^{-1}$; $^1H$ NMR (400 MHz, DMSO-$d_6$) $\delta$ 4.49 (s, 3H, 3CH), 7.17–7.91 (m, 30H, Ar–H + $3NH_2$).$^{13}C$ NMR (100 MHz, DMSO-$d_6$) $\delta$ 36.8, 58.3, 104.2, 113.5, 117.1, 119.7, 122.1, 122.9,

125.2, 129.3, 133.4, 141.5, 150.7, 152.7, 154, 158.5, 160.1, 173.5. MS (EI, 70 eV): *m*/*z* (%) 1071 [$M^+$]. Anal. calcd for $C_{60}H_{33}N_9O_{12}$: C, 67.23; H, 3.10; N, 11.76. Found: C, 66.94; H, 2.88; N, 11.47.

### 2,2′,2″,2‴,2⁗,2⁗′-((((1,3,5-Triazine-2,4,6-triyl)tris(oxy)) tris(benzene-4,1-diyl)) tris (methanetriyl))hexakis(3-hydroxy-5,5-dimethylcyclohex-2-en-1-one) (21)

A mixture of tris-aldehyde **3** (1 mmol), dimedone **6** (6 mmol) and *p*-TSA (15 mol%) in ethanol/$H_2O$ (15 ml, 2 : 1) was heated at reflux for 6 h. The solid formed was collected and crystalized from EtOH to give **21** as colorless crystals; yield: 83%; mp 245–248 °C; (EtOH). IR (KBr) $\nu$ 3345 (OH), 1650 (C=O) $cm^{-1}$; $^1$H NMR (300 MHz, DMSO-$d_6$) $\delta$ 0.90 (s, 18H, $6CH_3$), 1.02 (s, 18H, $6CH_3$), 2.04–2.27 (m, 12H, 6 $CH_2$), 2.48–2.52 (m, 12H, $6CH_2$), 3.33 (br, 3H, 3OH), 4.42 (s, 3H, methine-H), 6.56–6.59 (d, *J* 8.7 Hz, 6H, Ar–H), 6.92–6.95 (d, *J* 8.7 Hz, 6H, Ar–H), 9.20 (br, 3H, 3OH). $^{13}$C NMR (75 MHz, DMSO-$d_6$) $\delta$ 26.4, 28.7, 30.1, 31.8, 40.1, 50.1, 114.6, 114.8, 128.9, 134.8, 155.6, 162.5, 196.1. MS (EI, 70 eV): *m*/*z* (%)1227 [$M^+$]. Anal. calcd for $C_{72}H_{81}N_3O_{15}$: C, 70.40; H, 6.65; N, 3.42. Found: C, 70.17; H, 6.38; N, 3.19.

### 2,4,6-Tris(4-(benzo[*d*]thiazol-2-yl)phenoxy)-1,3,5-triazine (24)

To a mixture of 2-aminothiophenol (3 mmol) **23**, tris-aldehyde **3** (1 mmol) in absolute ethanol (10 ml), sodium hydrogen sulfite (3 mmol) was added. The reaction mixture was heated at reflux for 4 h. The obtained solid was collected and crystalized from acetic acid to give **24** as pale yellow powder; yield: 61%; mp 200–202 °C. IR (KBr) $\nu$ 1568 (C=N) $cm^{-1}$; $^1$H NMR (400 MHz, DMSO-$d_6$) $\delta$ 7.42–8.13 (m, 24H, Ar–H).$^{13}$C NMR (100 MHz, DMSO-$d_6$) $\delta$ 121.5, 122.7, 123.1, 123.3, 126, 127.1, 129, 131.2, 135, 153.9, 166.6, 173.4. MS (EI, 70 eV): *m*/*z* (%) 756 [$M^+$]. Anal. calcd for $C_{42}H_{24}N_6O_3S_3$: C, 66.65; H, 3.20; N, 11.10. Found: C, 66.33; H, 3.03; N, 10.84.

### 2,4,6-Tris(4-(1*H*-phenanthro[9,10-*d*]imidazol-2-yl)phenoxy)-1,3,5-triazine (26)

To a solution of tris-aldehyde **3** (1 mmol) in absolute ethanol (10 ml), 9,10-phenanthrenequinone **25** (3 mmol) and ammonium acetate (5 mmol) were added. The reaction mixture was heated at reflux for 3 h. The formed crude solid was collected and crystalized from AcOH to give **26** as orange powder; yield: 81%; mp > 300 °C; (AcOH). IR (KBr) $\nu$ 3305 (NH), 1590 (C=N) $cm^{-1}$; $^1$H NMR (400 MHz, DMSO-$d_6$) $\delta$ 7.48–8.88 (m, 36H, Ar–H), 13.47 (s, 3H, 3NH).$^{13}$C NMR (100 MHz, DMSO-$d_6$) $\delta$ 122.3, 122.9, 124.2, 124.9, 125.6, 125.8, 127.4, 127.9, 128.3, 129.6, 129.8, 131.7, 135.7, 135.9, 137.5, 149.0, 153.1, 169.9, 172.6, 179.4. MS (EI, 70 eV): *m*/*z* (%)1005 [$M^+$]. Anal. calcd for $C_{66}H_{39}N_9O_3$: C, 78.79; H, 3.91; N, 12.53. Found: C, 78.46; H, 3.69; N, 12.32.

### 2,4,6-Tris(4-((2-(5-((4-chlorophenyl)diazenyl)-4-methylthiazol-2-yl) hydrazineylidene)methyl)phenoxy)-1,3,5-triazine (30)

To a solution of tris(aldehyde thiosemicarbazone) **28** (1 mmol) in ethanol/DMF (20 ml, 3 : 1) containing TEA (0.1 ml, 1 mmol), *N*-(4-chlorophenyl)-2-oxopropanehydrazonoyl chloride **29** was added. The reaction mixture was heated at reflux for 6 h. The formed solid was collected and crystalized from DMF to give **30** as crimson red crystals; yield: 85%; decompose: 218–224 °C; (DMF). IR (KBr) $\nu$ 3424 (NH) $cm^{-1}$; $^1$H NMR (400 MHz, DMSO-$d_6$) $\delta$ 2.56 (s, 9H, $3CH_3$), 7.28–7.35 (m, 18H, Ar–H), 7.84–7.86 (m, 6H, Ar–H), 8.62 (s, 3H, 3CH), 10.53 (s, 3H, 3NH). MS (EI, 70 eV): *m*/*z* (%) 1190 [$M^+$]. Anal. calcd for $C_{54}H_{41}C_{13}N_{18}O_3S_3$: C, 54.39; H, 3.47; N, 21.14. Found: C, 54.17; H, 3.23; N, 21.02.

### General method for the synthesis of tris(thiazoles) 33, 34, 36, 38 and 40

To a solution of tris(aldehyde thiosemicarbazone) **28** (1 mmol) in ethanol/DMF (20 ml, 3 : 1) containing TEA (0.1 ml, 1 mmol), the appropriate 2-bromoethanones **31**, **32**, **35**, **37** and **39** (3 mmol) were added. The reaction mixture was heated at reflux for 3 h. The formed crude solid was collected and crystalized from the proper solvents to give **33**, **34**, **36**, **38** and **40**.

### 2,4,6-Tris(4-((2-(4-phenylthiazol-2-yl)hydrazineylidene) methyl)phenoxy)-1,3,5-triazine (33)

Pale yellow powder; yield: 79%; mp 250–255 °C; (DMF). IR (KBr) $\nu$ 3434 (NH), 1564 (C=N) $cm^{-1}$; $^1$H NMR (300 MHz, DMSO-$d_6$) $\delta$ 7.20 (s, 3H, thiazole-H), 7.33–7.80 (m, 27H, Ar–H), 8.03 (s, 3H, CH), 12.21 (br, 3H, 3NH).$^{13}$C NMR (75 MHz, DMSO-$d_6$) $\delta$ 103.7, 121.8, 125.4, 127.2, 127.5, 128.5, 132.3, 134.6, 140.1, 151.8, 168.3, 172.9. MS (EI, 70 eV): *m*/*z* (%) 960 [$M^+$]. Anal. calcd for $C_{51}H_{36}N_{12}O_3S_3$: C, 63.73; H, 3.78; N, 17.49. Found: C, 63.49; H, 3.47; N, 17.23.

### 2,4,6-Tris(4-((2-(4-(4-chlorophenyl)thiazol-2-yl) hydrazineylidene)methyl) phenoxy)-1,3,5-triazine (34)

Pale yellow powder; yield: 81%; mp 265–267 °C; (DMF). IR (KBr) $\nu$ 3432 (NH), 1566 (C=N) $cm^{-1}$; $^1$H NMR (300 MHz, DMSO-$d_6$) $\delta$ 7.25 (s, 3H, thiazole-H), 7.32–7.35 (d, *J* 8.7 Hz, 6H, Ar–H), 7.42–7.39 (d, *J* 8.7 Hz, 6H, Ar–H), 7.68–7.71 (d, *J* 8.7 Hz, 6H, Ar–H), 7.77–7.80 (d, *J* 8.7 Hz, 6H, Ar–H), 8.03 (s, 3H, CH), 12.21 (br, 3H, 3NH).$^{13}$C NMR (75 MHz, DMSO-$d_6$) $\delta$ 104.4, 121.8, 127.1, 127.2, 128.5, 131.9, 132.3, 133.4, 140.2, 149.2, 151.8, 168.4, 172.9. MS (EI, 70 eV): *m*/*z* (%) 1062 [$M^+$]. Anal. calcd for $C_{51}H_{33}Cl_3N_{12}O_3S_3$: C, 57.55; H, 3.13; N, 15.79. Found: C, 57.36; H, 3.01; N, 15.44.

### 2,4,6-Tris(4-((2-(4-(3-methyl-1-phenyl-1*H*-pyrazol-4-yl)thiazol-2-yl) hydrazineylidene)methyl)phenoxy)-1,3,5-triazine (36)

Pale yellow powder; yield: 66%; mp 245–250 °C; (DMF). IR (KBr) $\nu$ 3427 (NH), 1565 (C=N) $cm^{-1}$; $^1$H NMR (300 MHz, DMSO-$d_6$) $\delta$ 2.47 (s, 9H, $3CH_3$), 6.84 (s, 3H, thiazole-H) 7.31–7.90 (m, 30H, Ar–H), 8.03 (s, 3H, CH), 12.18 (br, 3H, 3NH).$^{13}$C NMR (75 MHz, DMSO-$d_6$) $\delta$ 11.9, 101.8, 116.7, 121.8, 122.4, 124.9, 127.2, 127.7, 129.1, 132.4, 135.4, 138.7, 139.3, 168.1, 172.9. MS (EI, 70 eV): *m*/*z* (%) 1200 [$M^+$]. Anal. calcd for $C_{63}H_{48}N_{18}O_3S_3$: C, 62.99; H, 4.03; N, 20.99. Found: C, 62.71; H, 3.84; N, 20.68.

**2,4,6-Tris(4-((2-(4-(benzofuran-2-yl)thiazol-2-yl) hydrazineylidene)methyl) phenoxy)-1,3,5-triazine (38)**

Brown powder; yield: 62%; mp 270–275 °C; (DMF). IR (KBr) $\nu$ 3423 (NH), 1563 (C=N) $cm^{-1}$; $^1H$ NMR (300 MHz, DMSO-$d_6$) $\delta$ 7.03 (s, 3H, thiazole-H), 7.24–7.73 (m, 27H, Ar–H), 8.05 (s, 3H, 3CH), 12.26 (br, 3H, 3NH). MS (EI, 70 eV): $m/z$ (%)1080 [$M^+$]. Anal. calcd for $C_{57}H_{36}N_{12}O_6S_3$: C, 63.32; H, 3.36; N, 15.55. Found: C, 63.11; H, 3.07; N, 15.23.

**2,4,6-Tris(4-((2-(4-(benzo[*d*]thiazol-2-yl)thiazol-2-yl) hydrazineylidene) methyl)phenoxy)-1,3,5-triazine (40)**

Green crystals; yield: 76%; mp 265–270 °C; (DMF). IR (KBr) $\nu$ 3432 (NH), 1559 (C=N) $cm^{-1}$; $^1H$ NMR (300 MHz, DMSO-$d_6$) $\delta$ 7.32–8.05 (m, 27H, Ar–H), 8.05 (s, 3H, 3CH), 12.47 (s, 3H, 3NH). MS (EI, 70 eV): $m/z$ (%)1131 [$M^+$]. Anal. calcd for $C_{54}H_{33}N_{15}O_3S_6$: C, 57.28; H, 2.94; N, 18.56. Found: C, 57.03; H, 2.77; N, 18.29.

## Conflicts of interest

There are no conflicts to declare.

## References

1 Z. Luo, W. Xiong, T. Liu, W. Cheng, K. Wu, Y. Sun and C. Yang, *Org. Electron.*, 2016, **41**, 1–7.
2 Z. Hao, Y. Liu, Y. Huang, F. Meng, Y. Wang, H. Tan, S. Su and W. Zhu, *J. Organomet. Chem.*, 2017, **835**, 52–59.
3 A. Irfan, S. Muhammad, A. R. Chaudhry, A. G. Al-Sehemi and R. Jin, *Optik*, 2017, **149**, 321–331.
4 K. Rundel, S. Maniam, K. Deshmukh, E. Gann and C. R. Mcneill, *J. Mater. Chem. A*, 2017, **5**, 12266–12277.
5 C. Lu, I. T. Choi, J. Kim and H. K. Kim, *J. Mater. Chem. A*, 2017, **5**, 20263–20276.
6 H. Feng, X. Geng, J. Lin, H. Guo and F. Yang, *Liq. Cryst.*, 2018, **45**, 1470–1476.
7 F. A. Olate, M. L. Parra, J. M. Vergara, J. Barberá and M. Dahrouch, *Liq. Cryst.*, 2017, **44**, 1173–1184.
8 S. K. Pathak, S. Nath, J. De, S. K. Pal and A. S. Achalkumar, *New J. Chem.*, 2017, **41**, 4680–4688.
9 Y. N. Luponosov, J. Min, A. N. Solodukhin, O. V. Kozlov, M. A. Obrezkova, S. M. Peregudova, T. Ameri, S. N. Chvalun, M. S. Pshenichnikov, C. J. Brabec and S. A. Ponomarenko, *Org. Electron.*, 2016, **32**, 157–168.
10 D. Astruc, E. Boisselier and C. Ornelas, *Chem. Rev.*, 2010, **110**, 1857–1959.
11 D. L. Reger, R. F. Semeniuc and M. D. Smith, *Inorg. Chem. Commun.*, 2003, **42**, 8137–8139.
12 H. M. Diab, A. M. Abdelmoniem, M. R. Shaaban, I. A. Abdelhamid and A. H. M. Elwahy, *RSC Adv.*, 2019, **9**, 16606–16682.
13 P. Gamez, P. De Hoog, M. Lutz, A. L. Spek and J. Reedijk, *Inorg. Chim. Acta.*, 2003, **351**, 319–325.
14 G. Giacomelli, A. Porcheddu and L. Luca, *Curr. Org. Chem.*, 2005, **8**, 1497–1519.
15 L. Hu, J. Li, J. Huang and J. Yin, *Chin. J. Chem.*, 2017, **35**, 93–97.
16 M. Jung, K. H. Lee, J. Y. Lee and T. Kim, *Mater. Horiz.*, 2020, **7**, 559–565.
17 P. Bhagavath, R. Shetty and D. Sunil, *Crit. Rev. Solid State Mater. Sci.*, 2019, **45**, 1–32.
18 K. C. Majumdar, N. De, B. Roy and A. Bhaumik, *Liq. Cryst.*, 2010, **37**, 1459–1464.
19 S. Matsumura, A. R. Hlil, C. Lepiller, J. Gaudet, D. Guay, Z. Shi, S. Holdcroft and A. S. Hay, *J. Polym. Sci., Part A: Polym. Chem.*, 2008, **46**, 7207–7224.
20 K. K. Bansal, D. Kakde, U. Gupta and N. K. Jain, *J. Nanosci. Nanotechnol.*, 2010, **10**, 8395–8404.
21 B. N. Veerabhadraswamy, H. K. Dambal, D. S. S. Rao and C. V. Yelamaggad, *ChemPhysChem*, 2016, **17**, 2225–2237.
22 A. Laventure, G. De Grandpré, A. Soldera, O. Lebel and C. Pellerin, *Phys. Chem. Chem. Phys.*, 2016, **18**, 1681–1692.
23 Y. Wang, T. Li, Y. Yin, Y. Jiang, G. Wang, D. Liu and J. Hua, *Optik*, 2017, **142**, 163–167.
24 A. El-Faham, K. A. Dahlous, Z. A. A. L. Othman, H. A. Al-Lohedan and G. A. EL-Mahdy, *Molecules*, 2016, **21**, 1–11.
25 G. Blotny, *Tetrahedron*, 2006, **62**, 9507–9522.
26 Z. E. Koc, H. Bingol, A. O. Saf, E. Torlak and A. Coskun, *J. Hazard. Mater.*, 2010, **183**, 251–255.
27 R. V. Patel, P. Kumari, D. P. Rajani and K. H. Chikhalia, *Eur. J. Med. Chem.*, 2011, **46**, 4354–4365.
28 P. Gahtori and S. K. Ghosh, *J. Enzyme Inhib. Med. Chem.*, 2012, **27**, 281–293.
29 U. P. Singh, H. R. Bhat, P. Gahtori and R. K. Singh, *Silico pharmacol.*, 2013, **1**, 1–9.
30 V. K. Pandey, S. Tusi, Z. Tusi, M. Joshi and S. Bajpai, *Acta Pharm.*, 2004, **54**, 1–12.
31 V. Lozano, L. Aguado, B. Hoorelbeke, M. Renders, M. J. Camarasa, D. Schols, J. Balzarini, A. San-Félix and M. J. Pérez-Pérez, *J. Med. Chem.*, 2011, **54**, 5335–5348.
32 A. Agarwal, K. Srivastava, S. K. Puri and P. M. S. Chauhan, *Bioorg. Med. Chem. Lett*, 2005, **15**, 3133–3136.
33 P. Gahtori, S. K. Ghosh, P. Parida, A. Prakash, K. Gogoi, H. R. Bhat and U. P. Singh, *Exp. Parasitol.*, 2012, **130**, 292–299.
34 A. Baliani, G. J. Bueno, M. L. Stewart, V. Yardley, R. Brun, M. P. Barrett and I. H. Gilbert, *J. Med. Chem.*, 2005, **48**, 5570–5579.
35 F. Leroux, B. J. Van Keulen, J. Daliers, N. Pommery and J. P. Hénichart, *Bioorg. Med. Chem.*, 1999, **7**, 509–516.
36 B. R. Henke, T. G. Consler, N. Go, R. L. Hale, D. R. Hohman, S. A. Jones, A. T. Lu, L. B. Moore, J. T. Moore, L. A. Orband-Miller, R. G. Robinett, J. Shearin, P. K. Spearing, E. L. Stewart, P. S. Turnbull, S. L. Weaver, S. P. Williams, G. B. Wisely and M. H. Lambert, *J. Med. Chem.*, 2002, **45**, 5492–5505.
37 G. H. Kuo, A. DeAngelis, S. Emanuel, A. Wang, Y. Zhang, P. J. Connolly, X. Chen, R. H. Gruninger, C. Rugg, A. Fuentes-Pesquera, S. A. Middleton, L. Jolliffe and W. V. Murray, *J. Med. Chem.*, 2005, **48**, 4535–4546.
38 G. H. Kuo, A. DeAngelis, S. Emanuel, A. Wang, Y. Zhang, P. J. Connolly, X. Chen, R. H. Gruninger, C. Rugg,

A. Fuentes-Pesquera, S. A. Middleton, L. Jolliffe and W. V. Murray, *J. Med. Chem.*, 2005, **48**, 4535–4546.
39 J. Lloyd, H. J. Finlay, W. Vacarro, T. Hyunh, A. Kover, R. Bhandaru, L. Yan, K. Atwal, M. L. Conder, T. Jenkins-West, H. Shi, C. Huang, D. Li, H. Sun and P. Levesque, *Bioorg. Med. Chem. Lett.*, 2010, **20**, 1436–1439.
40 B. Kolesinska, K. Barszcz, Z. J. Kaminski, D. Drozdowska, J. Wietrzyk and M. Switalska, *J. Enzyme Inhib. Med. Chem.*, 2012, **27**, 619–627.
41 J. K. Srivastava, G. G. Pillai, H. R. Bhat, A. Verma and U. P. Singh, *Sci. Rep.*, 2017, **7**, 1–18.
42 M. Shanmugam, K. Narayanan, K. H. Hari Prasad, D. Karthikeyan, L. Chandrasekaran, R. Atchudan and V. Chidambaranathan, *New J. Chem.*, 2018, **42**, 1698–1714.
43 O. Prakash, D. K. Aneja, K. Hussain, P. Lohan, P. Ranjan, S. Arora, C. Sharma and K. R. Aneja, *Eur. J. Med. Chem.*, 2011, **46**, 5065–5073.
44 M. Henary, S. Paranjpe and E. A. Owens, *Heterocycl. Commun.*, 2013, **19**, 89–99.
45 M. M. Kamel and N. Y. Megally Abdo, *Eur. J. Med. Chem.*, 2014, **86**, 75–80.
46 N. Mibu, K. Yokomizo, K. Yamada, J. Matsuyama, S. Tomonaga, I. Sakai, R. Sato, Y. Kawano, Y. Matsumoto, Y. Fujita, Y. Inoue, M. Iida, K. Hashiguchi, J. R. Zhou, M. Furutachi and K. Sumoto, *Heterocycles*, 2019, **98**, 489–508.
47 H. R. Bhat, U. P. Singh, P. Gahtori, S. K. Ghosh, K. Gogoi, A. Prakash and R. K. Singh, *New J. Chem.*, 2013, **37**, 2654–2662.
48 R. Kaur, P. Kaur, S. Sharma, G. Singh, S. Mehndiratta, P. M. S. Bedi and K. Nepali, Recent Pat. Anticancer, *Drug Discovery*, 2014, **10**, 23–71.
49 A. Makowska, F. Saczewski, P. J. Bednarski, J. Saczewski and Ł. Balewski, *Molecules*, 2018, **23**, 1–16.
50 M. E. Salem, A. F. Darweesh, A. M. Farag and A. H. M. Elwahy, *J. Heterocycl. Chem.*, 2017, **54**, 586–595.
51 A. H. M. Elwahy, R. M. Sarhan and M. A. Badawy, *Curr. Org. Synth.*, 2013, **10**, 786–790.
52 M. E. Salem, A. F. Darweesh, A. M. Farag and A. H. M. Elwahy, *Tetrahedron*, 2016, **72**, 712–719.
53 N. A. Abd El-Fatah, A. F. Darweesh, A. A. Mohamed, I. A. Abdelhamid and A. H. M. Elwahy, *Tetrahedron*, 2017, **73**, 1436–1450.
54 M. F. Mohamed, A. F. Darweesh, A. H. M. Elwahy and I. A. Abdelhamid, *RSC Adv.*, 2016, **6**, 40900–40910.
55 I. A. Abdelhamid, A. F. Darweesh and A. H. M. Elwahy, *Tetrahedron Lett.*, 2015, **56**, 7085–7088.
56 M. E. Salem, M. Hosny, A. F. Darweesh and A. H. M. Elwahy, *Synth. Commun.*, 2019, **49**, 2319–2329.
57 H. M. Diab, I. A. Abdelhamid and A. H. M. Elwahy, *Synlett*, 2018, **29**, 1627–1633.
58 M. E. Salem, A. F. Darweesh, M. R. Shaaban and A. H. M. Elwahy, *Arkivoc*, 2019, (part v), 73–88.
59 M. Hosny, M. E. Salem, A. F. Darweesh and A. H. M. Elwahy, *J. Heterocycl. Chem.*, 2018, **55**, 2342–2348.
60 A. M. S. Hebishy, M. S. Abdelfattah, A. Elmorsy and A. H. M. Elwahy, *Synth. Commun.*, 2020, **50**, 980–996.
61 M. E. Salem, A. A. Ahmed, A. F. Darweesh, O. Kühn and A. H. M. Elwahy, *J. Mol. Struct.*, 2019, **1176**, 19–30.
62 M. E. Salem, A. F. Darweesh and A. H. M. Elwahy, *Synth. Commun.*, 2020, **50**, 256–270.
63 A. M. Abdelmoniem, S. A. S. Ghozlan, D. M. Abdelmoniem, A. H. M. Elwahy and I. A. Abdelhamid, *J. Heterocycl. Chem.*, 2017, **54**, 2844–2849.
64 A. M. Abdella, M. F. Mohamed, A. F. Mohamed, A. H. M. Elwahy and I. A. Abdelhamid, *J. Heterocycl. Chem.*, 2018, **55**, 498–507.
65 N. A. A. El-Fatah, A. F. Darweesh, A. A. Mohamed, I. A. Abdelhamid and A. H. M. Elwahy, *Monatsh. Chem.*, 2017, **148**, 2107–2122.
66 S. K. Salama, M. F. Mohamed, A. F. Darweesh, A. H. M. Elwahy and I. A. Abdelhamid, *Bioorg. Chem.*, 2017, **71**, 19–29.
67 O. M. Sayed, A. E. M. Mekky, A. M. Farag and A. H. M. Elwahy, *J. Sulfur Chem.*, 2014, **36**, 124–134.
68 F. G. Khan, M. V. Yadav and A. D. Sagar, *Med. Chem. Res.*, 2014, **23**, 2633–2638.
69 H. Duan, L. Wang, D. Qin, X. Li, S. Wang and Y. Zhang, *Synth. Commun.*, 2011, **41**, 380–384.
70 M. Bashiri, A. Jarrahpour, B. Rastegari, A. Iraji, C. Irajie, Z. Amirghofran, S. Malek-Hosseini, M. Motamedifar, M. Haddadi, K. Zomorodian, Z. Zareshahrabadi and E. Turos, *Monatsh. Chem.*, 2020, **151**, 821–835.
71 E. M. Awad, N. M. Elwan and H. M. Hassaneen, *Helv. Chim. Acta*, 2001, **84**, 1172–1180.
72 F. M. Saleh, H. M. Hassaneen, H. Butenschön, G. Dräger and I. A. Abdelhamid, *Tetrahedron Lett.*, 2019, **60**, 151265.
73 T. Josephrajan and V. T. Ramakrishnan, *Can. J. Chem.*, 2007, **85**, 572–575.
74 M. Idris, C. Coburn, T. Fleetham, J. Milam-Guerrero, P. I. Djurovich, S. R. Forrest and M. E. Thompson, *Mater. Horiz.*, 2019, **6**, 1179–1186.
75 Z. Chang, X. Jing, C. He, X. Liu and C. Duan, *ACS Catal.*, 2018, **8**, 1384–1391.
76 C. J. J. Goddard, *Heterocycl. Chem.*, 1991, **28**, 1607–1612.
77 I. Mohammed-Ziegler, A. Hamdi, R. Abidi and J. Vincens, *Supramol. Chem.*, 2006, **18**, 219–234.