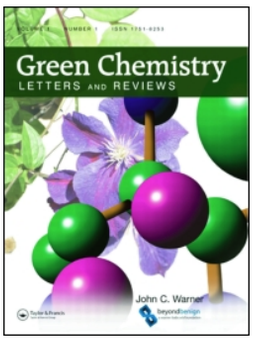


Green Chemistry Letters and Reviews

ISSN: 1751-8253 (Print) 1751-7192 (Online) Journal homepage: http://www.tandfonline.com/loi/tgcl20

Microwave synthesis and fluorescence properties of homo- and heterodimeric monomethine cyanine dyes TOTO and their precursors

Hussein H. Alganzory, Wael A. El-Sayed, Mohamed H. Arief, Mahasen S. Amine & El-Zeiny M. Ebeid

To cite this article: Hussein H. Alganzory, Wael A. El-Sayed, Mohamed H. Arief, Mahasen S. Amine & El-Zeiny M. Ebeid (2017) Microwave synthesis and fluorescence properties of homo- and heterodimeric monomethine cyanine dyes TOTO and their precursors, Green Chemistry Letters and Reviews, 10:1, 10-22, DOI: 10.1080/17518253.2016.1258088

To link to this article: http://dx.doi.org/10.1080/17518253.2016.1258088

Published online: 09 Dec 2016.

GREEN CHEMISTRY LETTERS AND REVIEWS, 2016
VOL. 10, NO. 1, 10–22
http://dx.doi.org/10.1080/17518253.2016.1258088

Taylor & Francis
Taylor & Francis Group

Microwave synthesis and fluorescence properties of homo- and heterodimeric monomethine cyanine dyes TOTO and their precursors

Hussein H. Alganzory [a,b], Wael A. El-Sayed [c], Mohamed H. Arief[a], Mahasen S. Amine[a] and El-Zeiny M. Ebeid[d,e]

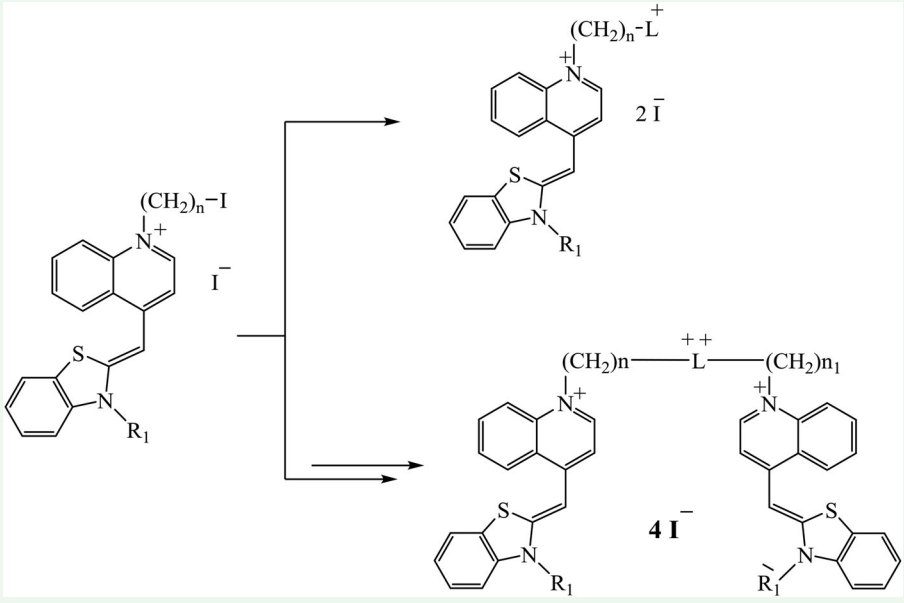
[a]Chemistry Department, Faculty of Science, Benha University, Benha, Egypt; [b]Chemistry Department, Faculty of Science, Qassim University, Buraydah, Qassim, Saudi Arabia; [c]Photochemistry Department, National Research Centre, Dokki, Cairo, Egypt; [d]Chemistry Department, Faculty of Science, Tanta University, Tanta, Egypt; [e]Misr University for Science and Technology (MUST), Giza, Egypt

ABSTRACT

A series of monomeric and dimeric cyanine dyes belonging to the thiazole orange family have been prepared via an improved synthetic procedure, by the reaction of the monomethine dye containing an iodoalkyl group with tertiary diamine linkers under microwave irradiation. The effects of microwave power and irradiation time on yield were examined. The electronic absorption and steady-state fluorescence spectra of prepared dyes have been investigated. Fluorescence properties indicate significance in singlet oxygen sensitization and make the present compounds potential candidates in the area of photodynamic therapy.

ARTICLE HISTORY
Received 30 June 2015
Accepted 3 November 2016

KEYWORDS
Microwave; monomethine cyanine dyes; TOTO's analogues; singlet oxygen



1. Introduction

Interest in nonradioactive DNA stains that are stable under gel electrophoretic conditions has led to the synthesis and characterization of a family of homo- and heterodimeric DNA-binding dyes (*1–3*). Organic fluorescent probes (FPs) are, as a rule, polycyclic aromatic cations with the planar structure capable of incorporating (intercalating) between the planes of the DNA bases, pulling apart these planes and changing the structure of nucleic acids. Binding with nitrogen bases enhances the fluorescence intensity of the probe compared to the free molecule (in solution), and this property of FP is widely used in various fields of molecular biology and biochemistry. Tetra cationic bis-intercalators cyanine dyes; 1-(3-((3-(dimethyl(3-(4-((Z)-(3-methylbenzo[d]thiazol-2(3H)-ylidene)methyl)quinolin-1-ium-1-yl)propyl)-ammonio)propyl)(metheyliumyl)(methyl)-l4-azanyl)-propyl)-4-((Z)-(3-methylbenzo[d]thiazol-2(3H)-ylidene)methyl)quinolin-1-ium TOTO-1 (Figure 1) and their analogues occupy the most important class among bis-intercalating dyes (*4, 5*). They have a higher affinity to DNA than mono-intercalators dicationic thiazole orange (TO) (*6, 7*), since these bis-intercalators contain two intercalating groups. Bis-intercalating TOTO-1 dyes have a weak fluorescence in the free state, but they sharply (more than 1000 times) increase fluorescence due to binding

CONTACT Hussein H. Alganzory h_ganzory@yahoo.com

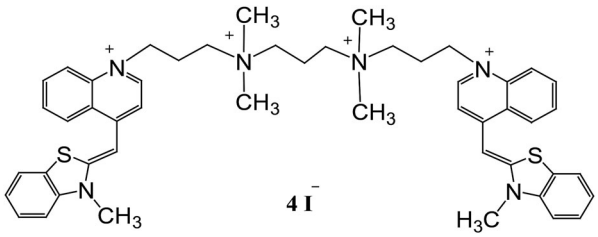


Figure 1. TOTO dye.

with DNA (*4*) and, therefore, they are widely used in biological, medical and drug development areas as fluorescent labels and probes (*8–15*). They found also applications in genetic studies and modern diagnostic methods (*1–3*), for examples, in the case of the polymerase chain reaction for cancer diagnostics at early stages of the disease; for diagnostics of infection diseases (*1–4*), including AIDS; for the identification of DNA samples in criminal law (*16, 17*); flow cytometry (*18*), DNA sequencing (*19, 20*) and quantification of nucleic acids in capillary and gel electrophoresis (*21–23*). Besides, they are commonly applied to lasers (*24*), electronics (*25*), nonlinear optics (*26*) and solar cells (*27*).

According to the classical method, bis-intercalating TOTO families were synthesized by the reaction of the monomethine dye containing a haloalkyl group with tertiary diamine linkers in DMF for 12 h as minimum (*5, 28–33*). In some cases, the reaction required long time and may exceed 3 days followed by the addition of methanol and keeping of the reaction mixture at 0°C and in this case, the yield of the product does not exceed 25% (*3*). Thus, the problem of improvement of methods for their synthesis seems to be urgent. Therefore, we report a rapid and more efficient method to synthesize these types of very important dyes by using microwave irradiation. The reported method achieves the Greenness approach in the manuscript in addition to the approach that it does not require additional recrystallization/purification steps, which are often necessary and can be demanding for these types of reactions. Microwave irradiation presents a powerful tool toward organic reactions and is known as environmentally benign method, which offers several advantages, including shorter reaction times, cleaner reaction profiles and simple experimental/product isolation procedures (*34–36*).

In addition to this developed synthetic method, the electronic absorption and steady-state fluorescence spectra were also reported.

2. Experimental

2.1. Measurements

Melting points were taken on a XT-4 micromelting apparatus and are uncorrected. IR spectra were recorded with PERKIN ELMER MODEL 1720 FTIR spectrometer. ^{1}HNMR and ^{13}C-NMR spectra were measured with a Varian EM 390 and Bruker AC-250 spectrometers respectively. The chemical shifts in ppm are expressed in the δ scale using tetramethylsilane (Me_4Si) as internal standard. Coupling constants are given in Hz. Fast Atom Bombardment Mass Spectrometry [FAB-MS] were recorded in a Micromass Autospec M, operating at 70 eV, using a matrix of 3-nitrobenzyl alcohol. UV–VIS absorption spectra were recorded on a Shimadzu UV-1700 UV–VIS spectrometer. Fluorescence spectra were recorded on a Hitachi F-4500 Spectrofluorimeter. TLC was performed on Merck silica gel 60-F 254 precoated plastic plates.

2.2. Synthetic procedure

Monomethine cyanine dyes $\mathbf{1_{a-f}}$ were prepared in good yields via microwave-assisted solvent-free method according to our previously reported method (*37*).

A series of mono-intercalators dicationic thiazole orange (TO) $\mathbf{2_{a-f}}$ and bis-intercalating tetra cationic (TOTO) $\mathbf{3_{a-h}}$ dyes were successfully synthesized with high yields of 75–90% within 78–110 min using modified microwave irradiation at 70–120 watts in the presence of DMF and few drops of triethyl amine as a base (Schemes 1, 2).

It is necessary to emphasize that the dyes $\mathbf{2_a}$, $\mathbf{2_b}$, $\mathbf{2_f}$ and $\mathbf{3_a}$ were previously synthesized by classical methods according to literatures (*28, 29*) and were used for other purposes.

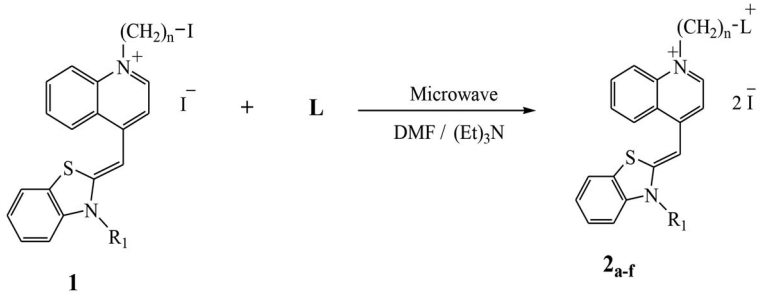
The chemical structures of prepared (TOTO) $\mathbf{3_{a-h}}$ dyes and their corresponding starting materials are listed (Table 1).

All microwave reactions were conducted using Start S Milestone S/N 129802 microwave apparatus.

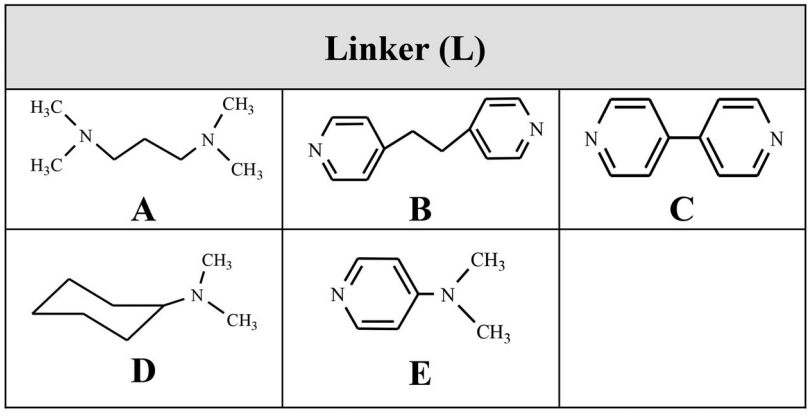
2.2.1. General procedure for preparation of dicationic cyanine diamino derivatives dyes (2_{a-f})

A mixture of equivalent amount of monomethine cyanine dyes **1** (1 mmol) and corresponding diamino linker **L** (1 mmol) in the presence of DMF (20 mL) and few drops of triethylamine is subjected to microwave irradiation with stirring for proper time and power. The reaction progress was monitored by TLC (eluent, Pet. ether : ethyl acetate, 3 : 1). The precipitates that formed were filtered off, washed with CH_2Cl_2 and dried at 60°C. The details of reaction conditions and yields are provided in Table 2 and the optimizing process for experimental conditions of dye $\mathbf{2_d}$ is listed in Table 3.

2.2.1.1. 1-[3-[[3-(dimethylamino)propyl]dimethylammonio]propyl]-4-[(3-methyl-2(3H)-benzothiazolylidene)methyl]-quinolinium, iodide (2_d). Reddish orange crystals, m.p.: 230–231°C; IR (KBr): $\nu = 1519$, 1612 cm^{-1}



Dyes 2_{a-f}	R_1	L	n
2_a	CH_3	A	3
2_b	CH_3	C	3
2_c	CH_3	D	3
2_d	CH_3	E	3
2_e	CH_2CH_3	A	3
2_f	CH_2Ph	A	3

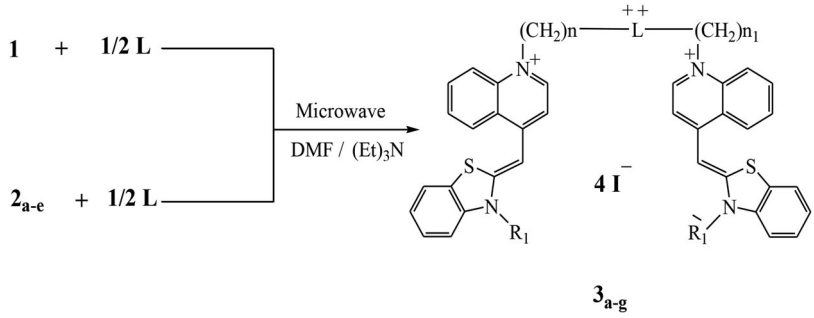


Scheme 1. Microwave synthesis of monomeric thiazole orange (TO) $2_{a,f}$.

(C=C, C=N); ^{1}HNMR (DMSO-d_6): δ (ppm) = 1.80–187 (m, 2H, CH_2), 2.14 (s, 6H, $N(CH_3)_2$), 2.23–2.32 (m, 4H, $2CH_2$), 3.07 (s, 6H, $2CH_3$), 3.28–3.36 (m, 2H, CH_2), 3.50–3.61 (m, 2H, CH_2), 4.06 (s, 3H, NCH_3), 4.62–4.71 (m, 2H, NCH_2), 6.97 (s, 1H, =CH), 7.42–7.58 (m, 4H, Ar-H), 7.72–7.85 (m, 3H, Ar-H), 8.72–8.85 (m, 3H, Ar-H); ^{13}CNMR: δ (ppm) = 19.9, 22.4 ($2CH_2$), 33.9 (NCH_3), 44.9 ($N(CH_3)_2$), 50.3 ($N^+(CH_3)_2$), 50.7 (NCH_2), 55.5 (NCH_2), 59.7 (CH_2), 62.3 (NCH_2), 88.4 (=CH), 107.8, 113.1, 117.8, 122.8, 123.9, 124.1, 124.6, 125.5, 126.71, 128.2, 133.3, 136.9, 140.4, 144.1, 148.5 (Ar-C), 160.4 (NCS).

2.2.1.2. 1-(4,4-bipyridyl)-4-[(3-methyl-3H-benzothiazol-2-ylidene)methyl[] quinolinium diiodide (2_b).

Reddish brown crystals, m.p.: 223–224°C; FAB = 615(742–127), 488(615–127); ^{1}HNMR (DMSO-d_6): δ (ppm) = 2.66–2.73 (m, 2H, CH_2), 4.00 (s, 3H, NCH_3), 4.79 (t, J = 6.8 Hz, 2H, CH_2), 4.88 (t, J = 6.8 Hz, 2H, CH_2), 6.88 (s, 1H, =CH),



Dyes 3_{a-g}	R_1	R_1^-	L	n	n_1
3_a	CH_3	CH_3	B	3	3
3_b	CH_3	CH_3	A	4	4
3_c	CH_3	CH_3	A	5	5
3_d	CH_2CH_3	CH_2CH_3	A	3	3
3_e	CH_2CH_3	CH_2CH_3	A	4	4
3_f	CH_3	CH_3	A	3	4
3_g	CH_2Ph	CH_3	A	3	3

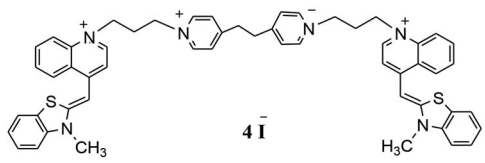
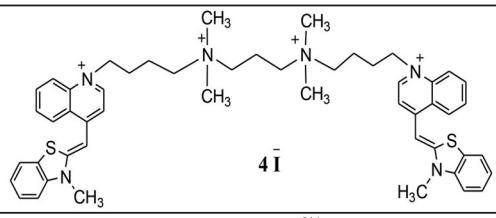
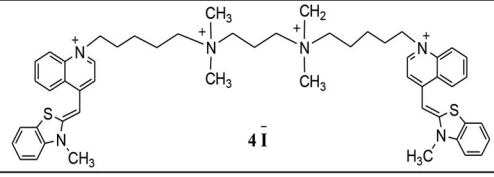
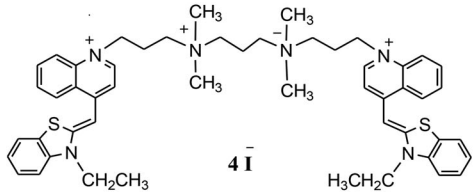
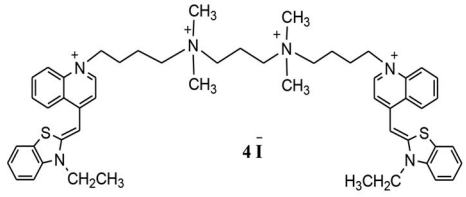
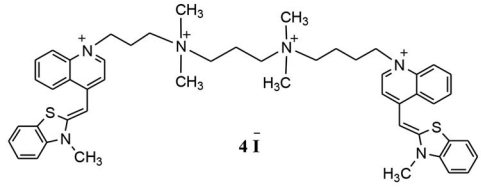
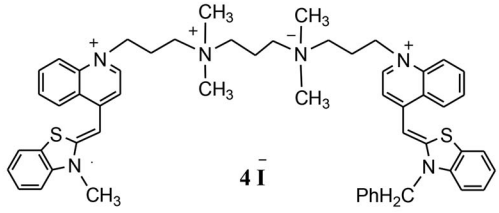
Scheme 2. Microwave synthesis of homo-and hetero-dimmeric TOTO's dyes 3_{a-g}.

7.26–7.44 (m, 5H, Ar-H), 7.59–7.75 (m, 3H, Ar-H), 7.95–8.14 (m, 4H, Ar-H), 8.39–8.57 (m, 2H, Ar-H), 8.97–9.26 (m, 4H, Ar-H); ^{13}CNMR: δ (ppm) = 29.7 (CH_2), 33.9 (NCH_3), 51.0, 57.7 ($2NCH_2$), 88.5 (=CH), 107.7, 113.1, 118.0, 121.6, 122.8, 123.8, 124.0, 124.6, 125.2, 126.7, 128.1, 133.2, 136.8, 140.3, 140.5, 142.0, 145.2, 148.4, 150.8, 152.2 (Ar-C), 160.3 (NCS); $C_{31}H_{28}N_4SI_2{+}H_2O$ (760); C, 48.96; H, 3.98, N, 7.37; Found: C, 48.77; H, 4.06, N, 6.99.

2.2.1.3. 1-(N,N-dimethylcyclohexanamine)-4-[(3-methyl-3H-benzothiazol-2-ylidene)methyl[] quinolinium diiodide (2_c). Reddish orange crystals, m.p.: 210–211°C; FAB = 586 (713–127), 459 (586–127); ^{1}HNMR (DMSO-d_6): δ (ppm) = 1.88–2.42 (m, 12H, $6CH_2$), 3.01 (s, 6H, $N^+(Me)_2$), 3.37 (t, J = 6.6 Hz, 2H, NCH_2), 3.54 (m, 1H, NCH), 4.04 (s, 3H, NCH_3), 4.65 (t, J = 6.6 Hz, 2H, NCH_2), 6.94 (s, 1H, =CH), 7.39–7.55 (m, 4H, Ar-H), 7.70–7.85 (m, 3H, Ar-H), 8.71–8.83 (m, 3H, Ar-H); $C_{29}H_{37}N_3SI_2$ (713.51); C, 48.82; H, 5.23, N, 5.89; Found: C, 49.48; H, 5.31, N, 5.86.

2.2.1.4. 1-(N,N-dimethyl-4-pyridinamine)-4-[(3-methyl-3H-benzothiazol-2-ylidene)methyl(]quinolinium diiodide (2_d). Reddish orange crystals, m.p.: 287–288°C; FAB = 581(708–127), 454 (581–127); IR (KBr): ν = 1512, 1612 cm^{-1} (C=C, C=N); ^{1}HNMR (DMSO-d_6): δ (ppm) = 2.42–2.51 (m, 2H, CH_2), 3.17 (s, 6H, $2CH_3$), 4.04 (s, 3H, CH_3), 4.41 (t, J = 6.8 Hz, 2H, CH_2), 4.69 (t, J = 6.8 Hz, CH_2), 6.92 (s, 1H, =CH), 7.02–7.18 (m, 4H, Ar-H), 7.49–7.65 (m, 3H, Ar-H), 7.98–8.35 (m, 5H, Ar-H), 8.68–8.81 (m, 2H, Ar-H); ^{13}CNMR: δ (ppm) = 29.6, 51.1, 53.9 ($3CH_2$), 33.9 (CH_3), 39.7 ($2CH_3$), 88.2 (=CH), 107.6, 107.8, 113.0, 117.9, 122.8, 123.8, 124.1, 124.5, 125.8, 126.7, 128.1, 133.2, 136.9, 140.3, 141.7, 144.0, 148.4, 155.7 (Ar-C), 160.2 (NCS); $C_{28}H_{30}I_2N_4S$ (708.4); C, 46.29; H, 4.44, N, 7.71; Found: C, 46.02; H, 4.50, N, 7.45.

Table 1. Structures and starting compounds of dimmeric thiazole orange (TOTO) cyanine dyes (3_{a-g}).

Dye 3	Structures	Starting comp.
3_a		1_a+ 1/2 B
3_b		1_d + 1/2 A
3_c		1_f+ 1/2 A
3_d		1_b + 1/2 A
3_e		1_d + 1/2 A
3_f		1_b + 2_a
3_g		1_c + 2_a

2.2.1.5. 1-(N,N′- tetramethyl-1,3-propane diamino)-4-[(3-ethyl-3H-benzothiazol-2-ylidene)methyl(]quinolinium diiodide (2_e). Red crystals, m.p.: 235–236°C; FAB = 603 (730–127), 476 (603–127); ^{1}HNMR (DMSO-d_6): δ (ppm) = 1.40 (t, J =7.1 Hz, 3H, CH_3), 1.83–1.91 (m, 2H, CH_2), 2.14 (s, 6H, $2CH_3$), 2.25–2.39 (m, 4H, $2CH_2$), 3.08

Table 2. The reaction conditions and yields for dicationic cyanine derivatives dyes (2_{a-f}).

Dyes	Power (W)	Time (min)	Yield (%)
2_a	100	90	90
2_b	120	110	80
2_c	100	100	87
2_d	100	90	85
2_e	100	90	81
2_f	110	100	85

Table 3. The effect of microwave power and irradiation time on dye 2_b.

Power (W)	Time (min)	Yield (%)
80	50	45
80	55	48
80	60	58
80	63	57
90	60	65
90	70	73
90	75	68
100	75	75
100	85	87
100	90	91
100	93	88

(s, 6H, $2CH_3$), 3.30–3.42 (m, 2H, CH_2), 3.53–3.64 (m, 2H, CH_2), 4.65–4.82 (m, 4H, $2CH_2$), 6.96 (s, 1H, =CH), 7.38–7.55 (m, 4H, Ar-H), 7.70–7.86 (m, 3H, Ar-H), 8.69–8.84 (m, 3H, Ar-H); ^{13}CNMR: δ (ppm) = 12.3 (CH_3), 19.9 (CH_2), 22.4 (CH_2), 41.2 (CH_2), 44.9 ($2CH_3$), 50.3 (CH_3), 50.7 (CH_2), 87.7 (=CH), 107.8, 112.8, 117.8, 123.0, 124.1, 124.6, 125.9, 126.8, 128.3, 133.3, 136.9, 139.4, 144.0, 148.7 (Ar-C), 159.4 (NCS).

2.2.1.6. 1-(N,N′- tetramethyl-1,3-propanediamino)-4-[(3-benzyl-3H-benzothiazol-2-ylidene)methyl[] quinoliniumdiiodide (2_f).

Reddish orange crystals, m.p.: 219–220°C; FAB = 665 (792–127); ^{1}HNMR (DMSO-d_6): δ (ppm)= 1.83–1.92 (m, 2H, CH_2), 2.01 (s, 6H, $2CH_3$), 2.23–2.46 (m, 4H, $2CH_2$), 3.03 (s, 6H, $2CH_3$), 3.32 (t, J = 6.8 Hz, 2H, CH_2), 3.50 (t, J = 6.4 Hz, 2H, CH_2), 4.55–4.58 (m, 2H, CH_2), 6.00 (s, 2H, CH_2), 7.02 (s, 1H, =CH), 7.29–7.44 (m, 4H, Ar-H), 7.71–7.85 (m, 3H, Ar-H), 7.98–8.28 (m, 5H, Ar-H), 8.52–8.68 (m, 3H, Ar-H); ^{13}CNMR: δ (ppm) = 19.9 (CH_2), 22.2 (CH_2), 40.7 ($2CH_3$), 44.9 ($2CH_3$), 50.3, 50.9, 55.5, 59.6, 62.1, ($5CH_2$), 88.6 (=CH), 108.1, 113.1, 118.0, 123.1, 123.8, 124.2, 124.8, 125.5, 126.6, 126.9, 127.8, 128.4, 128.9, 133.4, 135.0, 137.0, 140.3, 144.5, 148.8 (Ar-C), 159.9 (NCS); $C_{34}H_{42}N_4SI_2$+$3H_2O$ (846.8); C, 48.23; H, 5.71, N, 6.62; found: C, 48.56; H, 4.86, N, 6.12.

2.2.2. General procedure for preparation of homo-dimeric TOTO's analogue dyes (3_{a-e})

A mixture of monomethine cyanine dyes **1** (1 mmol) and corresponding diamino linker **L** (1 mmol) in the presence of DMSO (10 mL) and few drops of triethylamine was subjected to microwave irradiation with stirring for proper time and power. The precipitates that formed were filtered off, washed with hot acetone and dried at 60°C. The details of reaction conditions and yields are provided in Table 4.

Table 4. The reaction conditions and yields for homo- and heterodimeric TOTO's analogues dyes (3_{a-g}).

Dyes	Power (W)	Time (min)	Yield (%)
3_a	80	110	89
3_b	90	110	87
3_c	80	90	85
3_d	85	90	80
3_e	85	100	80
3_f	80	78	78
3_g	70	80	85

2.2.2.1. 1,1′-(1,2-di(4-pyridyl)-ethane)-bis-4-[(3-methyl-2,3-dihydro-2(3H)-benzo-1,3-thiazole)methyl] quinolinium tetraiodide 3_a.

Reddish brown crystals,, m.p.: 269–270°C; ^{1}HNMR (DMSO-d_6): δ (ppm) = 2.63–2.77 (m, 4H, $2CH_2$), 3.29–3.42 (m, 4H, $2CH_2$), 3.98 (s, 6H, $2CH_3$), 4.76–4.85 (m, 8H, $4CH_2$), 6.89 (s, 2H, 2=CH), 7.19–7.30 (m, 5H, Ar-H), 7.42–7.59 (m, 4H, Ar-H), 7.78–8.02 (m, 4H, Ar-H), 8.26–8.42 (m, 5H, Ar-H), 8.55–8.69 (m, 4H, Ar-H), 8.82–9.05 (m, 6H, Ar-H); ^{13}CNMR: δ (ppm) = 29.4, 33.9, 51.1, 57.8, ($8CH_2$), 34.0 ($2CH_3$), 88.6 (2C=H), 107.6, 112.9, 118.0, 121.5, 122.9, 123.8, 124.0, 124.5, 125.1, 125.8, 126.7, 128.1, 133.2, 133.4, 136.7, 140.1, 143.9, 144.8, 148.2, 150.0 (Ar-C), 160.2, (2NCS); $C_{54}H_{52}N_6S_2I_4$ (1356.8); C, 47.80; H, 3.86, N, 6.19; Found: C, 47.67; H, 3.97, N, 6.28.

2.2.2.2. 1,1′-(5,5,9,9-tetramethyl-5,9-diazatrideca-meth-ylene)-bis[4-[3-methyl-2,3-dihydro(benzo-1,3-thiazole)-2-methylidene]]quinolinium tetraiodide 3_b.

Reddish brown crystals,, m.p.: 259–260°C; FAB = 1203 (1330–127), 1076 (1203–127); IR (KBr): ν = 1519, 1612 cm^{-1} (C=C, C=N); ^{1}HNMR (DMSO-d_6): δ (ppm) = 1.93–2.12 (m, 8H, $4CH_2$), 2.30–2.41 (m, 2H, CH_2), 3.34 (s, 12H, $4CH_3$), 3.69 (t, J = 6.8 Hz, 4H, $2CH_2$), 3.57–3.64 (bt, 4H, $2CH_2$), 3.95 (s, 6H, $2CH_3$), 4.62–4.69 (bt, 4H, $2CH_2$), 6.77 (s, 2H, 2=CH), 7.15–7.27 (m, 5H, Ar-H), 7.40–7.55 (m, 4H, Ar-H), 7.77–7.92 (m, 4H, Ar-H), 8.22–8.38 (m, 3H, Ar-H), 8.56–8.70 (m, 4H, Ar-H); $C_{51}H_{62}N_6S_2I_4$+$2H_2O$ (1366.88); C, 44.82; H, 4.87, N, 6.15; Found: C, 44.73; H, 4.90; N, 5.78.

2.2.2.3. 1,1′-(6,6,10,10-tetramethyl-6,10-diazapenta dca- methylene)-bis[4-[3-methyl-2,3-dihydro(benzo-1,3- thiazole)-2-methylidene]]quinoliniumtetraiodide 3_c.

Red crystals, m.p.: 254–255°C; FAB = 1231(1358–127), 1104 (1231–127); IR (KBr): ν = 1469 (SH), 1519, 1612 cm^{-1} (C=C, C=N); ^{1}HNMR (DMSO-d_6): δ (ppm) = 1.43–1.52 (m, 4H, $2CH_2$), 1.83–1.93 (m, 4H, $2CH_2$), 5.88–5.87 (m, 4H, $2CH_2$), 2.22–2.29 (m, 2H, CH_2), 3.13 (s, 12H,

$4CH_3$), 3.36–3.42 (m, 8H, $4CH_2$), 3.98 (s, 6H, $2CH_3$), 4.58–4.70 (m, 4H, $2CH_2$), 6.82 (s, 2H, 2=CH), 7.23–7.38 (m, 5H, Ar-H), 7.52–7.68 (m, 4H, Ar-H), 7.84–7.96 (m, 4H, Ar-H), 8.28–8.39 (m, 3H, Ar-H), 8.58–8.76 (m, 4H, Ar-H); ^{13}CNMR: δ (ppm) = 16.8, 21.5, 22.6, 28.3, 53.5, 59.4, 63.2, ($13CH_2$), 33.9 ($2CH_3$), 50.4 ($4CH_3$), 88.0 (2=CH), 107.6, 112.8, 117.9, 122.7, 123.7, 124.0, 124.3, 125.7, 126.6, 128.0, 133.1, 136.8, 140.2, 144.0, 148.2 (Ar-C), 159.8 (2NCS); $C_{53}H_{66}N_6S_2I_4$+3H_2O (1413); C, 45.04; H, 5.18, N, 5.95; Found: C, 44.67; H, 5.14, N, 5.69.

2.2.2.4. 1,1′-(4,4,8,8-tetramethyl-4,8-diazaundecamethyl ene)-bis-4-[(3-ethyl-2,3-dihydro-2(3H)-benzo-1,3-thiazole) methyl]quinolinium tetraiodide 3_d.

Red crystals, m.p.: 249–250°C; FAB = 1203 (1330–127); ^{1}HNMR (DMSO-d_6): δ (ppm) = 1.37–1.45 (bt, 6H, $2CH_3$), 2.33–2.46 (m, 6H, $3CH_2$), 3.19 (bs, 12H, $4CH_3$), 3.34–3.45 (m, 4H, $2CH_2$), 3.68–3.79 (m, 4H, $2CH_2$), 4.65–4.75 (m, 8H, $4CH_2$), 6.93 (bs, 2H, 2=CH), 7.34–7.58 (m, 5H, Ar-H), 7.70–7.86 (m, 4H, Ar-H), 7.95–8.12 (m, 4H, Ar-H), 8.38–8.49 (m, 3H, Ar-H), 8.68–8.82 (m, 4H, Ar-H); ^{13}CNMR: δ (ppm) = 12.3 ($2CH_3$), 16.9 (CH_2), 22.5 ($2CH_2$), 38.5 ($2CH_2$), 41.2 ($2CH_2$), 50.7 ($4CH_3$), 59.9 ($2CH_2$), 60.4 ($2CH_2$), 87.7 (2=CH), 107.8, 112.9, 117.9, 122.9, 123.9, 124.0, 124.6, 125.9, 126.8, 128.3, 133.3, 136.9, 139.4, 143.9, 148.6, (Ar-C), 159.4 (NCS); $C_{51}H_{62}N_6S_2I_4$ (1330.9); C, 46.03; H, 4.70, N, 6.31; Found: C, 46.28; H, 4.85; N, 6.10.

2.2.2.5. 1,1′-(5,5,9,9-tetramethyl-5,9-diazatrideca-meth-ylene)-bis[4-[3-ethyl-2,3-dihydro(benzo-1,3-thiazole)-2-methylidene]]quinolinium tetraiodide 3_e.

Reddish brown crystals, m.p.: 252–253°C; FAB = 1231 (1258–127); ^{1}HNMR (DMSO-d_6): δ (ppm) = 1.38 (t, 6H, J = 5.3, $2CH_3$), 1.90–2.04 (m, 8H, $4CH_2$), 2.23–2.39 (m, 2H, $2CH_2$), 3.16 (s, 12H, $4CH_3$), 3.38–3.40 (m, 4H, $2CH_2$), 3.47–3.59 (m, 4H, $2CH_2$), 4.64–4.79 (m, 8H, $4CH_2$), 6.88–6.93 (s, 2H, 2=CH), 7.32–7.46 (m, 5H, Ar-H), 7.63–7.78 (m, 4H, Ar-H), 7.96–8.11 (m, 4H, Ar-H), 8.37–8.45 (m, 3H, Ar-H), 8.66–8.79 (m, 4H, Ar-H); ^{13}CNMR: δ (ppm) = 12.3 ($2CH_3$), 19.3 ($4CH_2$), 25.7 (CH_2), 41.1 ($2CH_2$), 43.4 ($2CH_2$), 50.4 ($4CH_3$), 53.3 ($2CH_2$), 59.7 ($2CH_2$), 87.5 (2=CH), 107.9, 112.8, 118.0, 122.9, 124.0, 124.5, 124.9, 125.8, 126.8, 128.3, 133.2, 136.8, 139.4, 144.0, 148.6, (Ar-C), 159.1 (NCS); $C_{53}H_{66}N_6S_2I_4$ (1358.9); C, 46.85; H, 4.90, N, 6.18; Found: C, 46.67; H, 5.25; N, 5.91.

2.2.3. Synthesis of 1,1′-(4,4,8,8-tetramethyl-4,8-diazadodecamethylene)-bis[4-[3-methyl-2,3-dihydro (benzo-1,3-thiazole)-2-methylidene]]quinolinium tetraiodide 3_f

A mixture of equimolar (N,N′-tetramethyl-1,3-propanediamino) propyelthiazole orange $\mathbf{2_a}$ (1 mmol) and 1-(3-lodobutyl)-4-[(3-methyl-3H-benzothiazol-2-ylidene)methyl (]quinolinium iodide $\mathbf{1_b}$ (1 mmol) in presence of DMSO (10 mL) and few drops of triethylamine is subjected to microwave irradiation with stirring for 70 min at 80 W. The solid product was filtered off, washed with hot acetone and dried at 60°C to afford reddish brown precipitate yield 88%., m.p.: 239–240°C; FAB = 1189 (1316–127), 1062 (1189–127); IR (KBr): ν = 1512, 1612 cm^{-1} (C=C, C=N); ^{1}HNMR (DMSO-d_6): δ (ppm) = 1.91–199 (m, 4H, $2CH_2$), 2.35–2.46 (m, 4H, $2CH_2$), 3.20 (bs, 12H, $4CH_3$), 3.38–4.48 (m, 4H, $2CH_2$), 3.40–3.46 (m, 2H, CH_2), 3.68–3.73 (bm, 2H, CH_2), 4.00 (bs, 6H, $2CH_3$), 4.64–4.75 (m, 4H, $2CH_2$), 6.86 (bs, 2H, 2=CH), 7.28–7.42 (m, 5H, Ar-H), 7.68–7.82 (m, 4H, Ar-H), 7.96–8.14 (m, 4H, Ar-H), 8.37–8.48 (m, 3H, Ar-H), 8.64–8.76 (m, 4H, Ar-H); $C_{50}H_{60}N_6S_2I_4$+4H_2O (1388.9); C, 43.24; H, 4.94, N, 6.05; Found: C, 42.80; H, 4.86; N, 5.70.

2.2.4. Synthesis of 1,1′-(4,4,8,8-tetramethyl-4,8-diazaundecamethylene)-[4-[3-(benzyl-2,3-dihydro-2-(3h)-benzothiazolylidene)methyl]quinolinium]-[4-[3-(methyl-2,3-dihydro-2-(3h)-benzothiazolylidene) methyl]quinolinium]tetraiodide 3_g

A mixture of equivalent amounts of (N,N′-tetramethyl-1,3-propane diamino) propyelthiazole orange $\mathbf{2_a}$ (1 mmol), 1-(3-Iodopropyl)-4-[(3-benzyl-3H-benzothiazol-2-ylidene)-methyl] quinolinium tetrafluoroborate $\mathbf{1_c}$ (1 mmol), DMSO (10 ml) and few drops of triethylamine is subjected to microwave irradiation with stirring for 70 min at 80 W. The solid product was filtered off, washed with hot acetone and dried at 60°C to afford dark red crystals precipitate yield 90%, m.p.: 229–230°C; FAB = 1251(1378–127); IR (KBr): ν = 1512, 1612 cm^{-1} (C=C, C=N); ^{1}HNMR (DMSO-d_6): δ (ppm) = 2.35–2.46 (m, 6H, $3CH_2$), 3.18–3.22 (bs, 12H, $4CH_3$), 3.36–3.48 (m, 4H, $2CH_2$), 3.68–3.80 (m, 4H, $2CH_2$), 4.01 (s, 3H, CH_3), 4.66–4.79 (m, 4H, $2CH_2$), 6.00 (s, 2H, NCH_2Ph), 6.90, 6.97 (2s, 2H, 2=CH), 7.33–7.47 (m, 4H, Ar-H), 7.55–7.69 (m, 5H, Ar-H), 7.88–8.01 (m, 3H, Ar-H), 8.27–8.40 (m, 6H, Ar-H), 8.48–8.59 (m, 3H, Ar-H), 8.68–8.82 (m, 4H, Ar-H); ^{13}CNMR: δ (ppm) = 17.1 (CH_2), 22.5 ($2CH_2$), 34.0 (NCH_3), 48.6, 50.3, 50.4, ($5CH_2$), 50.7 ($4CH_3$), 59.9, 60.3 ($2CH_2$), 88.4, 88.5 (2=CH), 107.6, 108.1, 112.9, 117.9, 118.1, 122.7, 123.0, 123.8, 123.9, 124.0, 124.5, 124.6, 125.4, 125.8, 126.6, 126.7, 126.8, 127.8, 128.0, 128.3, 128.9, 133.3, 133.4, 135.0, 136.8, 140.1, 140.2, 143.9, 144.2, 148.3, 148.5, (Ar-C), 159.8, 160.2 (2NCS); $C_{55}H_{62}N_6S_2I_4$ (1378.8); C, 45.53; H, 4.86, N, 5.79; Found: C, 45.49; H, 4.81, N, 5.81.

3. Results and discussion

3.1. Synthetic procedures

There are two main routes to modify molecular biology, especially fluorescence properties and intercalating

activity of this class of dyes with DNA. The first is via modification of the tertiary di-amino linkers, and the second by changing the alkyl substituent of benzothiazole nucleus. In this communication, we applied these two improvement strategies. *N,N,N′,N′*-tetramethyl-1,3-propanediamine (TMPDA) **L_A**; 1,2-di(4-pyridyl)- ethane **L_B**; 4,4-bipyridyl **L_C**; N,N-dimethylcyclohexanamine **L_D** and *N,N*-dimethyl-4-pyridinamine **L_E** are five tertiary di-amino linkers, which were used to modify new series of monomeric and dimeric thiazole orange (TO & TOTO) improved dyes. In addition, changing the methyl group of benzothiazole nucleus with ethyl and benzyl groups **(3_d, 3_e, 3_g)** improved the fluorescence properties of this class of dyes.

Dyes **$3_{f,g}$** were synthesized by equimolar reaction of monomeric thiazole orange **2_a** and monomethine cyanine dyes (**1_b** & **1_c**). The details of reaction conditions and yields are provided in Tables 2 and 4 and the optimizing process for experimental conditions for dye **2_d** is listed in Table 3.

In all investigated cases, we found that (TO) and (TOTO) dyes formation reactions preceded efficiently with high to excellent yield in short reaction time, compared with the classical refluxing method. It could be found that the yield increased obviously with prolonging irradiation time within a certain power until achieving optimized reaction time. It could also be found that the reaction yield decreases under lower power and the reaction time becomes shorter with the increase of microwave power. This indicates that the greater the microwave radiation power, the faster the reaction rate.

The constitution of the prepared compounds was secured by their elemental analysis, UV–VIS absorption spectra, IR, ^{1}HNMR, ^{13}CNMR; FAB-MS data. The most characteristic bands of FTIR spectra in KBr appeared at the range 1512–1612 cm^{-1} for (C=C, C=N).

The ^{1}H-NMR data are in accordance with the structure of synthesized dyes $2_{a–f}$ and $3_{a–g}$. The ^{1}HNMR spectrum of 3_a measured in DMSO-d_6 as a representative example can be seen in Figure 2.

All 52 protons are displayed. Multiplet peak at $\delta =$ 1.32 ppm suggested for the most shielded 4 protons corresponding to 2 CH_2 groups of 1,2-di(4-pyridyl)-ethane (linker B), as it is the furthest from any

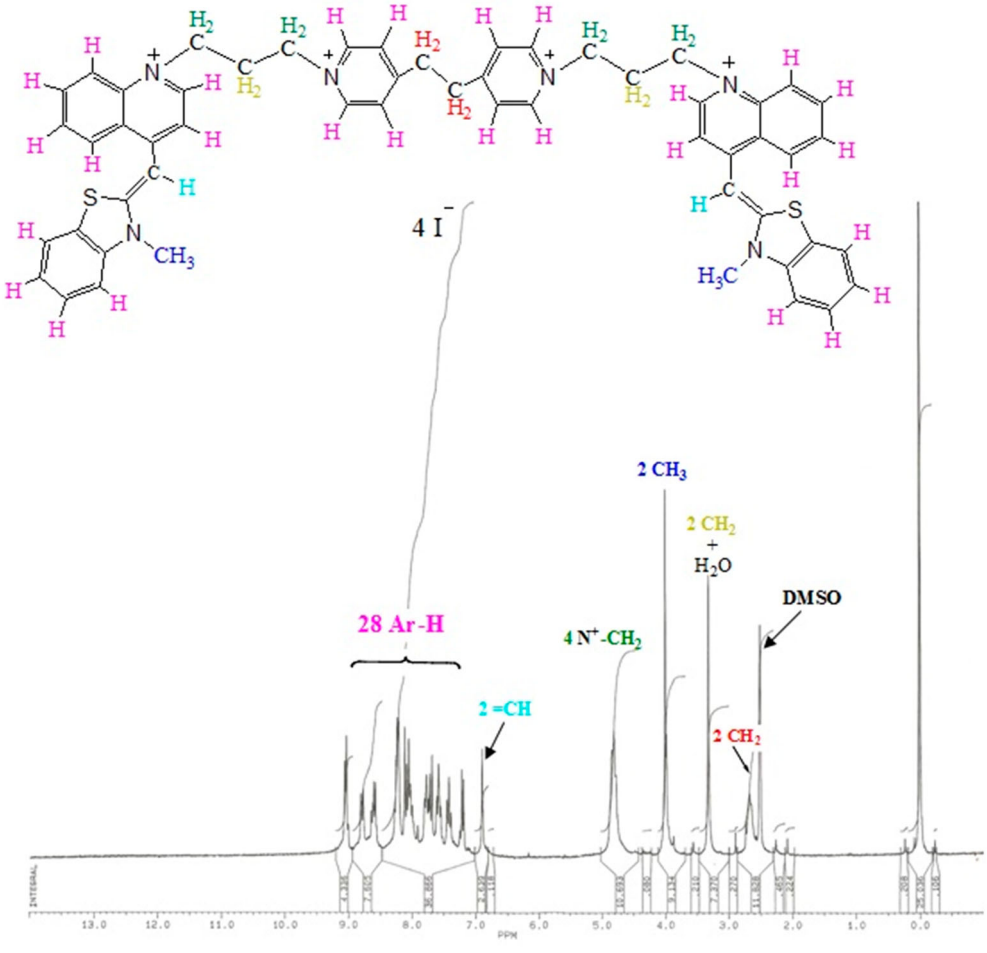


Figure 2. ^{1}H-NMR spectrum of 3_a in DMSO-d_6.

electronegative atoms. The two middle $-CH_2$ groups in propyl chain displayed as broad multiplet signal at $\delta =$ 3.32 ppm. The singlet signal at $\delta =$ 3.98 ppm for 6 protons corresponding to 2 $N-CH_3$ groups, these protons appeared at downfield region as they are deshielded with more electronegative nitrogen atom. The broad multiplet peak at $\delta = 4.81$ ppm for 8 protons corresponding to 4 N^+-CH_2- groups, as they deshielded with nitrogen atoms. The meso-protons of the methine (2=CH) groups displayed as singlet peak at higher chemical shift 6.86 as they are close to nitrogen atom and also to sulfur. Besides, 28 aromatic protons for phenyl and pyridyl rings displayed at rang $\delta = 7.19$ to 9.05 ppm, depending on the deshielding effect by the neighboring electronegative atoms. All ^{1}H-NMR spectra of all other synthesized dyes **2_{a-f}** and **3_{b-g}** could be interpreted as described for **3_a**.

2_{a-f} and **3_{b-g}** could be interpreted as described for **3_a**.

The ^{13}C-NMR spectrum of **3_a** measured in DMSO-d_6 shows all 45 carbons as seen in Figure 3.

Four carbons corresponding to 4 CH_2 groups of pyridyl and two middle for propyl appeared below $\delta =$ 50 ppm, at $\delta = 29.4$ and 33.9 ppm respectively. Four carbon atoms correspond to 4 $-N-CH_2$ groups displayed at higher chemical shift ($\delta > 50$ ppm) at 51.1 and 57.8 ppm as they are under the influence of nitrogen atom. The two carbons of methyl (2 CH_3) groups showed signal at $\delta =$ 34 ppm, while the two carbons corresponding to methine (2 =CH) groups resonate at $\delta =$ 88.6 ppm. Besides, 40 aromatic carbons show twenty signals at the regions 107.6, 112.9, 118.0, 121.5, 122.9, 123.8, 124.0, 124.5, 125.1, 125.8, 126.7, 128.1, 133.2, 133.4, 136.7, 140.1, 143.9, 144.8, 148.2, 150.0 ppm, the last two remaining two carbon atoms resonate at 160.2 ppm corresponding to (2 NCS) groups. All expected peaks of carbon atoms are seen.

All ^{13}C-NMR spectra of all synthesized **2_{a-f}** (TO) and **3_{b-g}** (TOTO) dyes could be interpreted using the same rules as described for **3_a** dye.

The structures of all synthesized dyes were confirmed by ^{1}H-NMR, ^{13}C-NMR, FTIR spectra, besides the correct elemental analysis and mass spectrum data, the elemental analysis of synthesized dyes showed correct analytical data.

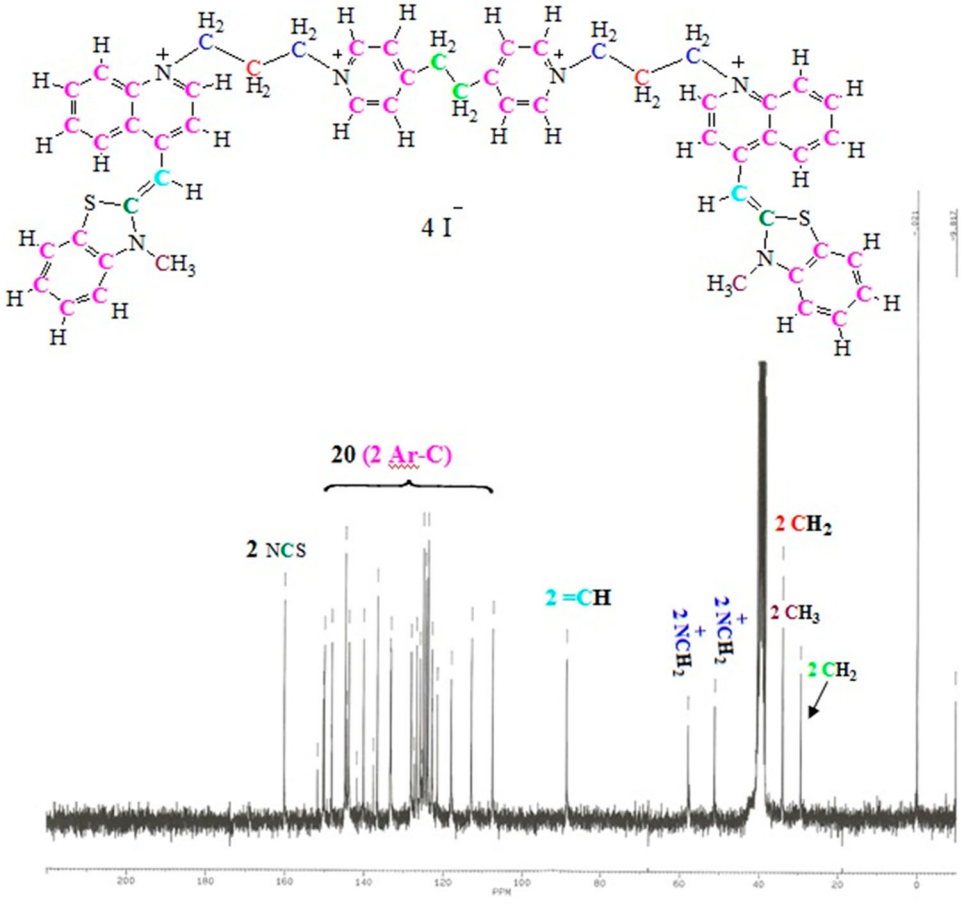


Figure 3. ^{13}C-NMR spectrum of 3_a in DMSO-d_6.

3.2. Fluorescence spectral study for some synthesized dyes

The electronic absorption spectra of the studied cyanine dyes are shown in Figures 4–9. The dyes are generally characterized by very small values of Stoke's shifts between absorption and emission spectral bands indicating that the absorption and emission photons exhibit close frequencies. Other emission broad bands in the near IR spectral range are also obtained that are attributed to phosphorescence and are good indication of triplet state formation. This becomes of great significance in singlet oxygen sensitization and makes the present compounds as potential candidates in the area of photodynamic therapy (PDT) (*38–40*).

At higher energies, a second excited electronic state absorption occurs around 290 nm. This second electronic state gives its characteristic fluorescence at around 390 nm. This is yet a peculiar behavior of these compounds since fluorescence dominates the internal conversion (ic) photophysical process.

The electronic absorption spectra of some compounds show two-split absorption peaks which are assigned to the first singlet-state absorption of monomeric and J-aggregates of the dye, which is a common phenomenon of many cyanine dyes (*41*, *42*). Cyanine molecules can form aggregates. Depending on the molecular orientation in these aggregate, J- and H-aggregates are formed. In J-aggregate, the molecules are aligned in a head to tail arrangement. In H-aggregate, molecular alignment is side – by – side. J-aggregates are characterized by sharp spectral bands that are red shifted with respect to the monomer and by a strong photoluminescence with almost zero stokes shift (*43*).

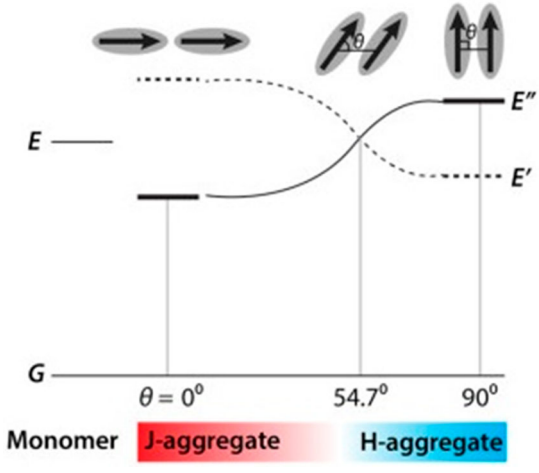


Figure 4. Monomer J- and H-aggregates. Adapted from ref. 43.

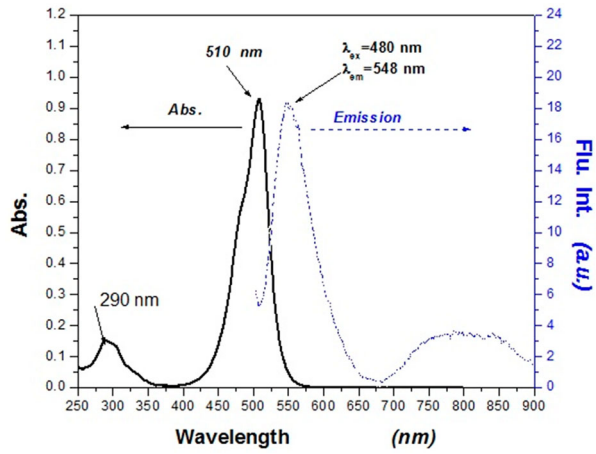


Figure 5. Full absorption and emission spectra of 1.2×10^{-5} M ethanolic solution of dye $\mathbf{2_a}$.

3.2.1. Compound [2_a]

The electronic absorption spectrum of compound $\mathbf{2_a}$ (Figure 5) shows two-split absorption peaks at 490 and 505 nm, which are assigned to the first singlet-state absorption of monomeric and J-aggregates of the dye (*41*, *42*). These lower energy J-aggregates give a symmetrical fluorescence peak of emission maximum at 548 nm (Figure 5). The symmetry of this peak, together with the fact that its spectral pattern does not alter upon excitation at 480 nm (absorption of monomeric species) or 510 nm (absorption of J-aggregates), indicates an energy transfer from higher energy monomeric species to lower energy aggregates during excited state lifetime. Like cyanine dyes, the compound is characterized by very small values of Stoke's shifts where absorption and emission photons exhibit close frequencies.

Another emission broad band in the spectral range 700–900 nm is also obtained that is attributed to

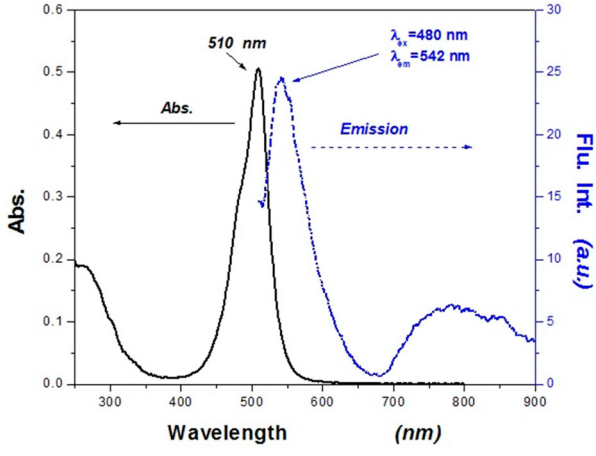


Figure 6. Full absorption and emission spectra of 7.6×10^{-6} M ethanolic solution of dye $\mathbf{2_b}$.

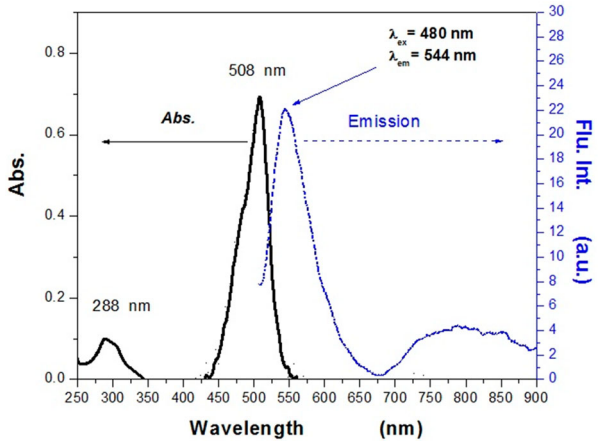


Figure 7. Full absorption and emission spectra of 1.1×10^{-5} M ethanolic solution of dye $\mathbf{2_e}$.

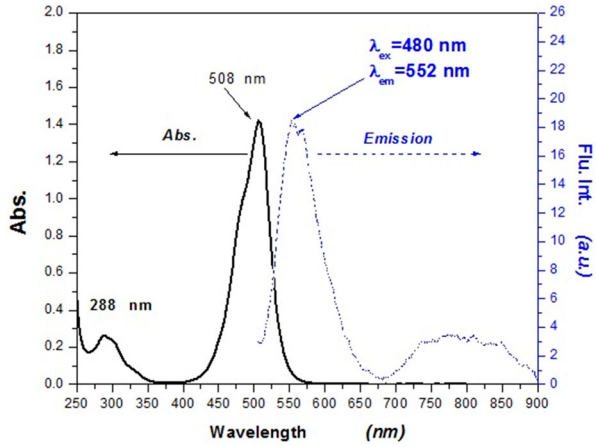


Figure 9. Full absorption and emission spectra of 1.5×10^{-5} M ethanolic solution of dye $\mathbf{3_f}$.

phosphorescence and is a good indication of triplet state formation. This becomes of great significance in singlet oxygen sensitization.

At higher energies, a second excited electronic state absorption occurs at 290 nm. This second electronic state gives its characteristic fluorescence at 390 nm. This is yet a peculiar behavior of this compound since fluorescence dominates the internal conversion (ic) photophysical process.

3.2.2. Compound [2_b]

The electronic absorption spectrum of compound $\mathbf{2_b}$ shows absorption peaks at 510 nm; a first excited electronic state absorption occurs at 510 nm. This first electronic state gives its characteristic fluorescence peak of emission maximum at 542 nm (upon excitation wavelength 480 nm).

Another emission broad band in the spectral range 680–900 nm is also obtained.

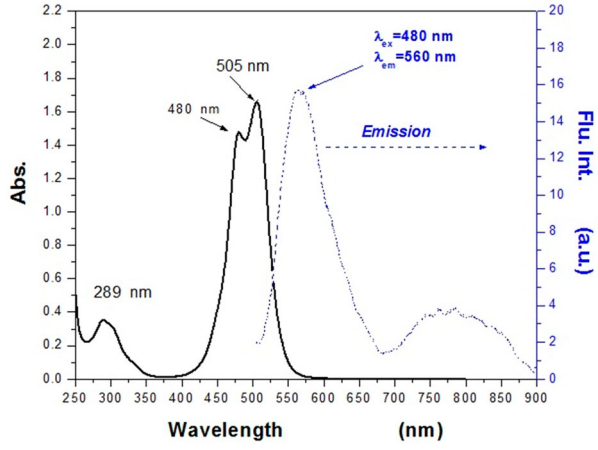


Figure 8. Full absorption and emission spectra of 1.6×10^{-5} M ethanolic solution of dye $\mathbf{3_c}$.

3.2.3. Compound [2_e]

The electronic absorption spectrum of compound $\mathbf{2_e}$ (Figure 7) shows absorption peak at 508 nm; this singlet-state absorption gives a symmetrical fluorescence peak of emission maximum at 544 nm. The spectral pattern does not alter upon excitation at 480 or 508 nm.

Another emission broad band in the spectral range 680–900 nm is also obtained that is attributed to phosphorescence.

At higher energies, a second excited electronic state absorption occurs at 288 nm. This second electronic state gives its characteristic fluorescence at 388 nm (Figure 7). This is yet a peculiar behavior of this compound since fluorescence dominates the internal conversion (ic) photophysical process.

3.2.4. Compound [3_c]

The electronic absorption spectrum of compound $\mathbf{3_c}$ (Figure 8) shows absorption peaks at 480 and 505 nm, which are assigned to the first singlet-state absorption of monomeric and J-aggregates of the dye (*41–42*). These lower energy J-aggregates give a symmetrical fluorescence peak of emission maximum at 560 nm. The symmetry of this peak together with the fact the its spectral pattern does not alter upon excitation at 480 nm (absorption of H-aggregates) or 505 nm (absorption of monomeric species) indicates an energy transfer from higher energy monomeric species to lower energy aggregates during excited state lifetime.

Another emission broad band in the spectral range 675–900 nm is also obtained that is attributed to phosphorescence.

At higher energies, a second excited electronic state absorption occurs at 289 nm (Figure 8). This second

electronic state gives its characteristic fluorescence at 385 nm. This is yet a peculiar behavior of this compound since fluorescence dominates the internal conversion (ic) photophysical process.

3.2.5. Compound [3_f]

The electronic absorption spectrum of compound **3_f** (Figure 9) shows absorption peak at 508 nm, a first excited electronic state absorption occurs at 508 nm, which gives its characteristic fluorescence peak of emission maximum at 552 nm upon excitation wavelength 480 nm. Another emission broad band in the spectral range 680–900 nm is also obtained that is attributed to phosphorescence.

At higher energies, a second excited electronic state absorption occurs at 288 nm. This second electronic state gives its characteristic fluorescence at 387 nm (Figure 9). This is yet a peculiar behavior of this compound since fluorescence dominates the internal conversion (ic) photophysical process.

Another emission broad band in the spectral range 680–900 nm is also obtained that is attributed to phosphorescence.

3.2.6. Compound [3_g]

The electronic absorption spectrum of compound **3_g** (Figure 10) shows absorption peak at 509 nm, a first excited electronic state absorption occurs at 509 nm. This first electronic state gives its characteristic fluorescence peak of emission maximum at 560 nm upon excitation wavelength 480 nm.

At higher energies, a second excited electronic state absorption occurs at 288 nm. This second electronic state gives its characteristic fluorescence at 385 nm.

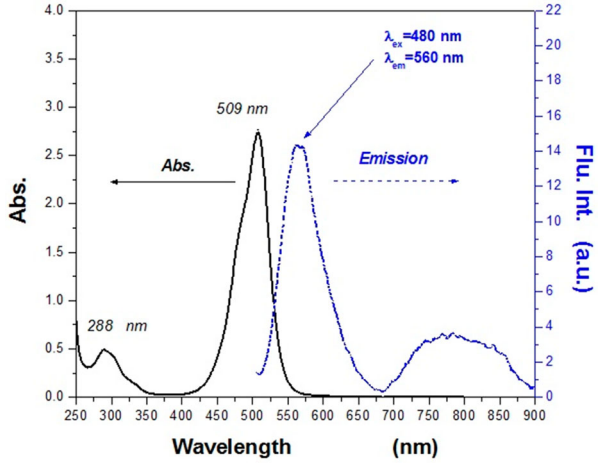


Figure 10. Full absorption and emission spectra of 2.2×10^{-5} M ethanolic solution of dye **3_g**.

4. Conclusions

We have described a rapid and highly efficient method for the synthesis of monomethine cyanine dyes with quinoline nucleus under microwave irradiation.

Both microwave-assisted reactions under solvent-free conditions and microwave-assisted reactions using (organic) solvents were used to synthesize a series of monomeric, homo and hetrodimmeric monomethine cyanine dyes. The Microwave technique showed several advantage**s** such as rapid reactions, high purity of products, less side-products, improved yields and simplified and improved synthetic procedure.

The electronic absorption and steady-state fluorescence spectra of prepared dyes revealed a potential use of these dyes as singlet oxygen sensitizers. The prepared dyes absorb in the region 477–516 nm and their fluorescence emissions are located at 542–900 nm. The dyes strong absorption peak around 500 nm coincides with green laser PDT that applies Ar^+ laser of $\lambda = 488$ nm in PDT treatment (*44*).

Disclosure statement

No potential conflict of interest was reported by the authors.

Notes on contributors

Hussein H. Alganzory is currently Assistant Professor of Organic Chemistry, Faculty of Science, Chemistry Department, Qassim University, Al-Qassim, KSA. He obtained his B.Sc. (1996) and M.Sc. (2008) degrees in organic chemistry from Menoufia University, Egypt. He obtained his Ph.D. degree (2015) from Benha University, Egypt. His research has focused on the new environmentally benign synthetic methods to synthesize the heterocyclic compounds by applying green chemistry protocols, studying structure-activity relationship of organic compounds and medicinal chemistry. He published 10 publications in international journals.

Wael A. El-Sayed is currently Associate Professor of Organic Chemistry, Photochemistry Department, National Research Centre, Cairo, Egypt. He obtained his B.Sc. (1996), M.Sc. (2001), and Ph.D. (2006) degrees in chemistry, organic chemistry from Menoufia University. The main research field is Organic and Medicinal Chemistry. He was granted a post-doctoral fellowship in Germany (Tubingen University, 2007) and also scientific mission in Poland (Selsia University, Katowice, 2008). He joined NBU University (Associate Prof. 2011-2014). He published more than 50 publications in international journals and works as a reviewer for a number of international indexed journals.

Mohamed H. Arief is currently Professor of Organic Chemistry, Faculty of Science, Chemistry Department Benha University, Egypt. He obtained his B.Sc., M.Sc. and Ph.D. degrees in chemistry from Benha University. His research has focused on the organic synthesis, chemical synthesis, degradation, mass

spectrometry, environment, multistep synthesis, heterocyclic chemistry, natural product chemistry. He published more than 65 publications in international journals.

Mahasen S. Amine is currently Professor Emeritus of Organic Chemistry, Faculty of Science, Chemistry Department Benha University, Egypt. Her research has focused on the organic synthesis, green chemistry, multistep organic synthesis, heterocyclic chemistry, natural product chemistry. She published 61 publications in international journals and works as a reviewer for a number of international indexed journals.

El-Zeiny M. Ebeid is currently Professor of Physical Chemistry, Faculty of Science, Tanta University, Egypt. He obtained his B.Sc. (1973) and M.Sc. (1976) degrees in chemistry from Tanta University. He obtained his Ph.D. degree (1980) in chemistry (Physical Chemistry) under joint supervision between Tanta University and University College of Wales, UK. He was a Visiting Lecturer at the University of Kent at Canterbury (1982-1983). He received the National Award in Chemistry (1986), awarded by the Egyptian National Academy of Science and Technology. He published more than 70 publications in international journals.

ORCID

Hussein H. Alganzory http://orcid.org/0000-0002-9426-5434
Wael A. El-Sayed http://orcid.org/0000-0002-8232-1830

References

[1] Benson, S.C.; Singh, P.; Glazer, A.N. *Nucleic Acids Res*. **1993**, *21*, 5727–5735.
[2] Benson, S.C.; Mathies, R.A.; Glazer, A.N. *Nucleic Acids Res*. **1993**, *21*, 5720–5726.
[3] Rye, H.S.; Yue, S.; Wemmer, D.E.; Quesada, M.A.; Mathies, R.P.; Glazer, A.N. *Nucleic Acids Res*. **1992**, *20*, 2803–2812.
[4] Rye, H.S.; Jonathan, M.D.; Quesada, M.A. *Anal. Biochem*. **1993**, *208*, 144–150.
[5] Deligeorgiev, T.G.; Gadjev, N.I.; Timcheva, I.; Maximova, V.A.; Katerinopolos, H.E.; Foukaraki, E. *Dyes Pigm*. **2000**, *44*, 131–136.
[6] Lee, L.G.; Chen, C.H.; Chiu, L.A. *Cytometry* **1986**, *7*, 508–517.
[7] US Pat. 4883867, *Chem. Abstr*., **1990**, *113*, 2982x.
[8] Yarmoluk, S.M.; Kryvorotenko, M.B.; Kovalska, V.B. *Dyes Pigm*. **2001**, *48*, 165–172.
[9] Yarmoluk, S.M.; Kovalska, V.B.; Kryvorotenko, D.V.; Balanda, A.O.; Ogul'chansky, T.Y. *Spectrochim Acta, Part A* **2001**, *57*, 1533–1540.
[10] Deligeorgiev, T.G.; Gadjev, N.I.; Vasilev, A.; Drexhage, K.H.; Yarmoluk, S.M. *Dyes Pigm*. **2006**, *70*, 185–191.
[11] Kovalska, V.B.; Luosytskyy, M.Y.; Yarmoluk, S.M. *Spectrochim Acta, Part A* **2001**, *57*, 1533.
[12] Yarmoluk, S.M.; Kovalska, V.B.; Lukashov, S.S.; Slominskii, Y.L. *Bioorg. Med. Chem. Lett*. **1999**, *9*, 1677–1678.
[13] Kovalska, V.B. *J. Fluorescence* **2002**, *12*, 209–212.
[14] Deligeorgiev, T.G.; Gadjev, N.I. *Dyes Pigm*. **1995**, *29*, 315–322.
[15] Kovalska, V.B.; Kyvorotenko, D.V.; Balanda, A.O.; Losytskyy, M.Y.; Tokar, V.P.; Yarmoluk, S.M. *Dyes Pigm*. **2005**, *67*, 47–54.
[16] Yarmoluk, S.M.; Kryvorotenko, D.V.; Balanda, A.O.; Losytskyy, M.Y.; Kovalska, V.B. *Dyes Pigm*. **2001**, *51*, 41–49.
[17] Patonay, G.; Salon, J.; Strekowski, L. *Molecules* **2004**, *9*, 40–49.
[18] Hirons, G.T.; Fawcett, J.J.; Crissman, H.A. *Cytometry* **1994**, *15*, 129–140.
[19] Selvin, P. *Science* **1992**, *257*, 885–886.
[20] Ju, J.; Glazer, A.N.; Mathies, R.A. *Nature Med*. **1992**, *2*, 246–249.
[21] Karlsson, H.J.; Eriksson, M.; Perzon, E.; Akerman, B.; Lincoln, P.; Westman, G. *Nucleic Acids Res*. **2003**, *31*, 6227–6234.
[22] Rye, H.S.; Quesada, M.A.; Peck, K.; Glazer, A.N. *Nucleic Acids Res*. **1991**, *19*, 327–333.
[23] Matselyukh, B.; Yarmoluk, S.M.; Matselyukh, A.B.; Kovalskal, V.B.; Kocheshev, I.O.; Kryvorotenko, D.V. *J. Biochem. Biophs. Methods* **2003**, *57*, 35–43.
[24] Zhao, C.F.; Gvishi, R.; Narang, U.; Ruland, G.; Prasad, P.N. *J. Phys. Chem*. **1996**, *100*, 4526–4532.
[25] Gromov, S.P.; Fedorova, O.A.; Ushakov, E.N.; Buevich, A.V.; Baskin, I.I.; Pershina, E.B.; Edlund, U.; MAlfimov, M.V. *J. Chem. Soc. Perkin Trans*. **1999**, *2*, 1323–1330.
[26] He, G.S.; Bhawalker, J.D.; Zhao, C.F.; Prasad, P.N. *Appl. Phys. Lett*. **1995**, *67*, 2433–2435.
[27] Haugland, R.P.; Spence, M.T.Z.; Johnson, I.D. *Handbook of Fluorescent Probes and Research Chemicals*. 6th ed.; Molecular Probes: Eugene, OR (4849 Pitchford Ave., Eugene 97402), **1996**.
[28] Staerk, D.; Hamed, A.A.; Pedersen, E.B.; Jacobsen, J.P. *Bioconjugate Chem*. **1997**, *8*, 869–877.
[29] Petersen, M.; Hamed, A.A.; Pedersen, E.B.; Jacobsen, J.P. *Bioconjugate Chem*. **1999**, *10*, 66–74.
[30] Gajev, N.I.; Deligeorgiev, T.G.; Timcheva, I.; Maximova, V.A. *Dyes Pigm*. **2003**, *57*, 161–164.
[31] Deligeorgiev, T.G.; Gadjev, N.I.; Vasilev, A.; Jacobsen, J.P.; Drexhage, K.H. *Dyes Pigm*. **2004**, *61*, 79–84.
[32] Vasilev, A.; Deligeorgiev, T.G.; Gadjev, N.I.; Drexhage, K.H. *Dyes Pigm*. **2005**, *66*, 135–142.
[33] Deligeorgiev, T.G.; Gadjev, N.I.; Vasilev, A.; Drexhage, K.H.; Yarmoluk, S.M. *Dyes Pigm*. **2007**, *72*, 28–32.
[34] Kuznetsov, D.V.; Raev, V.A.; Kuranov, G.L.; Arapov, O.V.; Kostikov, R.R. *Zh. Org. Khim*. **2005**, *41*, 1757–1787.
[35] Gabriel, C.O.; Gabriel, S.; Grant, E.H.; Haltstead, B.S.J.; Mingos, D.M.P. *Chem. Soc. Rev*. **1998**, *27*, 213–224.
[36] Bucharenko, A.L.; Frankevich, E.L. *Chemical Generation, Reception of Radio and Microwaves*; VCH: New York, NY, **1993**; 312 pp.
[37] Hussein, H.; Alganzory, M.M.H.; Arief, M.S.; Amine, M.S., Ebeid, El-Zeiny M. *J. Chem. Pharm. Res*. **2014**, *6*, (12), 143–161.
[38] Mingos, D.M.P.; Baghurst, D.R.; Kingston, H.M.; Hazel, S.J. ACS, Washington, DC, **1997**, 455.
[39] Nuchter, M.; Ondruschka, B.; Jungnickel, A.; Muller, U. *J. Phys. Org. Chem*. **2000**, *13*, 579–586; Nuchter, M.; Ondrushka, B.; Lautenschlager, W. *Synth. Commun*. **2001**, *37*, 1277–1283.
[40] Vanderhoff, J.W. U. S., 1969, 3, 432–413; Chem. Abstr. 1969; 70; 97422v.
[41] Eisfeld, A.; Briggs, J.S. *Chem. Phys*. **2006**, *324*, 376–384.
[42] *Rodd's Chemistry of Carbon Compounds*. Vol. IV B, 383–481. 2nd ed. Edited by M. Sainsbury; 1997 Elsevier science B.V.
[43] Kim, S.; Fujitsuka, M.; Tohnai, N.; Tachikawa, T.; Hisaki, I.; Miyata, M.; Majima, T. *Chem. Commun. (Camb)*. **2015**, *51*, 11580–11583.
[44] Brancaleon, L.; Moseley, H. *Lasers Med. Sci*. **2002**, *17*, 173–186.