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## **Seaweed consumption in France: key data for exposure and risk assessment**

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**Keywords:** seaweeds – food – consumption – enquiry – exposure and risk assessment

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1 **A novel benzotriazole derivate with Twisted Intramolecular**  
2 **Charge Transfer and Aggregation Induced Emission**  
3 **features for proton determination**

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14  
15 **Abstract:**

16 Molecules with Aggregation-Induced Emission (AIE) effects could show strong  
17 emission in solid or aggregate form, thus they are suitable for applications in the field  
18 of solid luminescent materials. **According to former** reporting, AIE molecules are  
19 always J-aggregates. In this study, a new benzotriazole derivate with electron donor-  
20 acceptor structure was synthesized. (E)-4-(2-(1H-benzo[d][1,2,3] triazol-1-yl) vinyl)-  
21 N, N-dimethylaniline (BTADA) has both TICT and AIE effect, even though it is H-  
22 aggregate. Furthermore, BTADA could **respond** to proton in solution and solid form.  
23 Due to its multiple binding sites, proton would bind to benzotriazole and  
24 dimethylaniline moiety successively when BTADA was exposed to acid, and the

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25 fluorescent color changed from green to yellow then blue as the concentration of  
26 proton increased. Such phenomena indicate BTADA has potential usage in proton  
27 detection.

28

29 **Keywords** Benzotriazole, H-aggregate, Aggregation-Induced Emission, Proton Response,  
30 Twisted Intramolecular Charge Transfer

31

## 32 **1. Introduction**

33 Normally, chromophoric organic dyes with planar structure always show strong  
34 luminescence **properties** in dispersed states, but the fluorescence will be **dramatically**  
35 quenched in solid or aggregate states because the energy from excited states can decay  
36 back via non-radioactive channels like  $\pi$ - $\pi$  stacking interactions between molecules  
37 [1], known as **Aggregation-Caused Quenching** (ACQ) [2, 3]. Compared with ACQ  
38 molecules, molecules with Aggregation-Induced Emission (AIE) effects could show  
39 strong fluorescence emission in solid or aggregate form. This effect was first brought  
40 by the group of Tang in 2001 [4], and has gained pile of attention since day one. Small  
41 organic molecules with AIE effect have stood out of the line due to the obvious  
42 advantages in some application fields. AIE molecules are suitable for applications in  
43 the field of solid luminescent materials because the luminescent molecules are  
44 required to be in a tightly packed aggregate or solid state [5, 6] rather than in a  
45 dispersed state in practical applications. **In the field of fluorescence analysis, the**

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46 ability of fluorescent probes to detect analytes in high water content systems is  
47 sometimes required. Because of hydrophobicity, the organic fluorescent molecules  
48 usually form aggregates in water. Traditional organic dyes suffer from ACQ effect and  
49 are restricted from application. However, AIE-based probes could be easily  
50 engineered and possess high photobleaching resistance. This kind probes can keep  
51 high sensitivity and selectivity to detect analytes in aqueous solution. Nowadays,  
52 these AIE organic molecules have been widely used in Organic Light-Emitting Diodes  
53 (OLEDs) [7 - 9], biosensor (for proteins [10 - 11], DNAs [12 - 14], amino acids [15 -  
54 17], and so on), chemosensor (for ions [18], gases [19], explosives [20 - 21] and so  
55 on) and other varies fields.

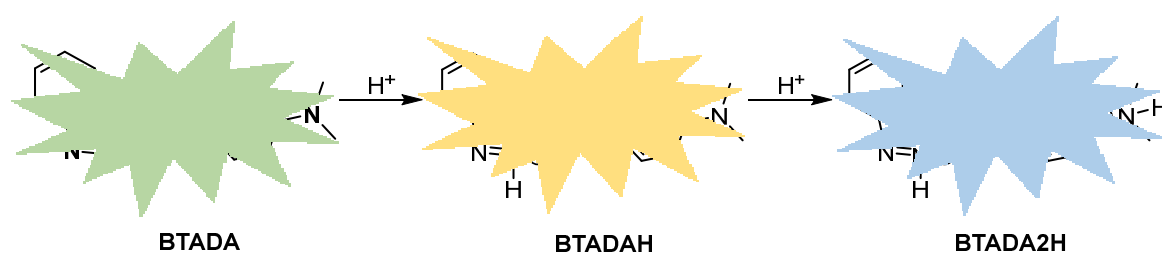
56 Many fluorescence molecules have an electron donor-acceptor (D-A) structure. In  
57 some cases, there is a bridge that link the electron donor part and the electron acceptor  
58 part in fluorescence molecules. When the external conditions change, such as  
59 temperature, pressure and polarity of the solvent, these molecules will twist as well.  
60 This kind of torsion leads to a charge separation among the whole molecule, narrows  
61 the band gap and results in red shift emission. This phenomenon is called “Twisted  
62 intramolecular charge transfer” (TICT) [22]. TICT effect of organic compounds have  
63 been systematically studied [23 - 25] and always used to detect some target molecules  
64 in analytical fields [26 - 28]. In recent years, organic fluorescence molecules with  
65 both TICT and AIE effects have attracted extensive attention and been applied in  
66 many analytical fields. Some of these TICT-AIE organic molecules like

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67 tetraphenylethene (TPE) derivatives [29], boron dipyrromethene (BODIPY)  
68 derivatives [30], cyan derivatives [31 - 33] and 9,10-Bis[4'-(4''-aminostyryl) styryl]  
69 anthracene derivatives [34] are J-aggregates when they generate AIE effect. **This**  
70 means they tend to pack in a “head-to-toe” form when these molecules aggregate. J-  
71 aggregates of AIE fluorescence molecules share as following characteristics: small  
72 Stokes-shift with a narrow band gap and a bathochromic shift of emission wavelength  
73 [35]. However, there’s another type of aggregation **in** which the molecules are packed  
74 “face-to-face”. Apart from J-aggregates, this kind of aggregation with a hypsochromic  
75 shift, is normally called “H-aggregate” [36 - 37]. H-aggregates have longer Stokes-  
76 shift than J-aggregates. Meanwhile, the UV-vis absorb and fluorescence emission  
77 spectra in aggregated states are blue shifted compared with those in dispersed states  
78 [35]. But, there are only a few reports about H-aggregate molecules in AIE  
79 luminogens. For example, Distyrylbenzene (DSB) [38] is a classic H-type AIE  
80 luminogens. Other examples include merocyanine and other dyes **containing**  
81 heteroaromatic rings [39 - 40]. However, it **comes** to our notice that benzotriazole  
82 derivatives as AIE fluorescence molecules are lack study. We **hereby reported** a new  
83 type of benzotriazole derivative that shows AIE effect while **aggregating** in the H-  
84 type.

85 Benzotriazole, compare to other heteroaromatic compounds, exhibits stronger  
86 aromaticity, flatter planarity, and can act like a much stronger electron-acceptor [41].  
87 **Naturally**, benzotriazole can play an important role among fluorescence organic

88 molecules. However, correlational research work is rarely reported. In this work, we  
89 synthesize (E)-4-(2-(1H-benzo[d][1,2,3] triazol-1-yl) vinyl)-N, N-dimethylaniline  
90 (BTADA). Due to its wide  $\pi$  conjugation and electron donor-acceptor construct,  
91 BTADA should exhibit high fluorescence emission in solution system. Following  
92 experiments **confirmed our conjecture**. Moreover, further experiments indicate other  
93 unexpected properties. In addition to exhibiting different fluorescence emission  
94 wavelength in **various** solvent, BTADA has strong fluorescence emissive activity in  
95 solid form. **The single-crystal structure of BTADA clearly shows that BTADA is a**  
96 **classic H-aggregate**. As discussed above, AIE property of benzotriazole derivative is  
97 rarely seen in H-aggregates. More to that, with the strong electron donor-acceptor  
98 structure of BTADA, the benzotriazole part and dimethylamine part are both rotors  
99 that can spin over the covalent bond on both sides of alkene bridge. Which makes it a  
100 classic TICT molecule. To summarize, during the aggregation of monomer, the  
101 BTADA shows TICT-AIE effect. Even more to the point, BTADA exhibited a dual-  
102 step response to proton, which means it has a potential application in proton detection.



104 **Scheme 1.** Schematic diagram of proton response of BTADA

## 105 **2. Experimental section**

### 106 *2.1. Materials and measurements*

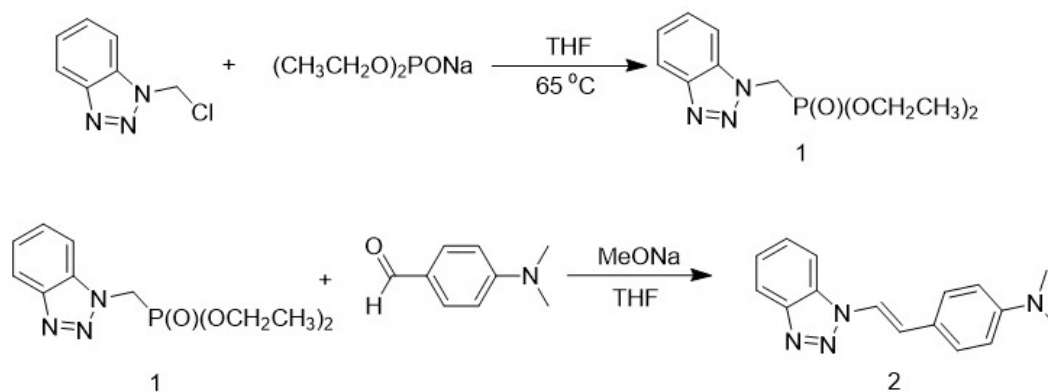
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107 All the raw materials were obtained from commercial supplies and used without  
108 further purification. THF were dehydrated by reflux with solid Na. Water used  
109 throughout all experiments was purified with Millipore system.  $^1\text{H}$  NMR and  $^{13}\text{C}$   
110 NMR spectra were recorded on Bruker 400 NMR spectrometer. Chemical shifts are  
111 reported in ppm with TMS as reference. Mass spectra were obtained with Agilent1290  
112 - Bruker microTOF QII mass spectrometer. The UV-vis absorption spectra were  
113 obtained using a Shimadzu UV-3100 Spectrophotometer. Fluorescence data was  
114 measured on a Hitachi F-2700 Fluor spectrophotometer.

115 The single crystal of BTADA was obtained from saturated dichloromethane  
116 solution by slow evaporation at room temperature. The crystallographic data for  
117 BTADA was collected on a Siemens Smart CCD diffractometer with graphite-  
118 monochromated Mo-K $\alpha$  ( $\lambda = 0.71073 \text{ \AA}$ ) radiation at room temperature. The structure  
119 was solved by direct methods with SHELXT1 and refined by full-matrix least-squares  
120 on  $F^2$  using the SHELXTL-20142. All non-hydrogen atoms were refined with  
121 anisotropic displacement parameters. The hydrogen atoms of the ligands were  
122 generated geometrically.

## 123 2.2. Synthesis of BTADA





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2

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**Scheme 2.** Synthesis route of BTADA

126

127 *2.2.1. Synthesis of Diethyl ((1H-benzo[d] [1,2,3] triazol-1-yl) methyl) phosphonate*

128 (1)

129 Diethyl ((1H-benzo[d] [1,2,3] triazol-1-yl) methyl) phosphonate (1) was  
 130 synthesized according to literature [42].

131 *2.2.2. Synthesis of BTADA*

132 MeONa (1.08 g, 20 mmol) and 1 (5.38 g, 20 mmol) was added to dry THF (20 ml)  
 133 under  $\text{N}_2$ , stirred at 0 °C for 30 minutes. After which the mixture of  
 134 4-Dimethylaminobenzaldehyde (1.49 g, 10 mmol) and THF (5ml) was slowly added  
 135 to the reaction solution with syringe. The reaction temperature was then heated to  
 136 reflux. After stirred for 12h under the protection of  $\text{N}_2$ , the reaction was quenched by  
 137 water. The aqueous solution was extracted with dichloromethane (3\*20ml) and the  
 138 combined organic phase was dried by  $\text{Na}_2\text{SO}_4$ . The solvent was removed by vacuum  
 139 evaporation. The crude product was purified by a silica gel column with ethyl acetate  
 140 and petroleum ether (1:5) as eluent, the products was obtained as yellow crystal in a

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141 yield of 90 % (2.38 g). <sup>1</sup>H NMR (400 MHz, Chloroform-*d*): δ 8.10 (d, *J* = 8.3 Hz,  
142 1H), 7.82 – 7.71 (m, 2H), 7.56 (ddd, *J* = 8.1, 6.9, 1.0 Hz, 1H), 7.48 – 7.35 (m, 4H),  
143 6.79 – 6.72 (m, 2H), 3.02 (s, 6H). <sup>13</sup>C NMR (101 MHz, Chloroform-*d*): δ 150.62,  
144 146.26, 131.52, 127.86, 127.77, 124.38, 122.34, 122.07, 120.31, 118.14, 112.42,  
145 110.23, 40.38. HRMS: *m/z* 265.1390 [(M+H)<sup>+</sup>, calcd 265.1409].

### 146 *2.3 fluorescence experiment*

147 The concentration of BTADA was  $1 \times 10^{-5}$  mol L<sup>-1</sup>, excitation wavelength was 365  
148 nm, excitation and emission slit were both 5 nm.

#### 149 *2.3.1 fluorescence response to different solvent*

150 BTADA was respectively dissolved in CH<sub>2</sub>Cl<sub>2</sub>, CHCl<sub>3</sub>, DMF, THF, Acetone,  
151 CH<sub>3</sub>CN, ethanol, ethyl acetate, toluene and cyclohexene. The final concentration of  
152 BTADA was  $1 \times 10^{-5}$  mol L<sup>-1</sup>.

#### 153 *2.3.2 fluorescence response to the water fraction of the solvent*

154 BTADA was dissolved in methanol, the concentration of BTADA was  $2 \times 10^{-4}$  mol  
155 L<sup>-1</sup>. Then 100 μL of BTADA **solution** was diluted with the mixture of methanol and  
156 water to 2 mL.

#### 157 *2.3.3 fluorescence response to the **viscosity** of the solvent*

158 BTADA was dissolved in methanol, the concentration of BTADA was  $2 \times 10^{-4}$  mol  
159 L<sup>-1</sup>. Then 100 μL of BTADA **solution** was diluted with the mixture of methanol and  
160 glycerol to 2 mL.

#### 161 *2.3.4 fluorescence response to proton*

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162 BTADA was dissolved in  $\text{CHCl}_3$ , the concentration of BTADA was  $2 \times 10^{-4} \text{ mol L}^{-1}$   
163 <sup>1</sup>. After different volume of trifluoroacetic acid (TFA,  $2.5 \times 10^{-3} \text{ mol L}^{-1}$ ) was added  
164 into BTADA solution, the mixed solution was diluted with  $\text{CHCl}_3$  to 2 mL.

### 165 3. Results and discussion

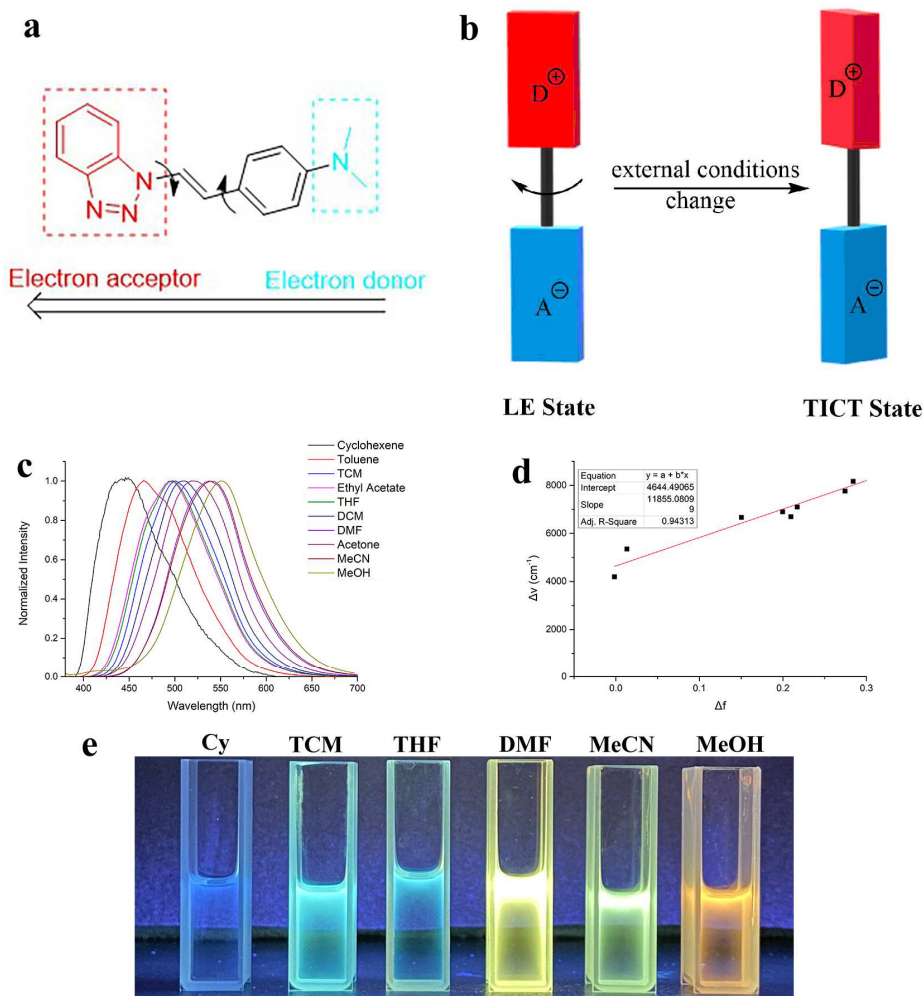
#### 166 3.1 Twisted intramolecular charge transfer

167 BTADA was synthesized through the above reaction procedures as yellow platy  
168 crystal. The total yield was 81%. As shown in Fig. 1a, BTADA contains a classic  
169 electron donor-acceptor structure. The N, N-dimethylamine part (electron donor) and  
170 the benzotriazole part (electron acceptor) in BTADA are connected through a  
171 conjugated  $\pi$ -bridge. The existence of rotatable C-C and C-N  $\delta$  bond on both sides of  
172 alkene bridge make them rotors. Meanwhile, the density functional theory (DFT) was  
173 used to calculate the charge distribution in BTADA. The results are shown in Fig. S3.  
174 In the highest occupied molecular orbital (HOMO) of BTADA, most of the electron  
175 density is on the N, N-dimethylamine part (electron donor), while in the lowest  
176 unoccupied molecular orbital (LUMO) of BTADA, most of the electron density is on  
177 the benzotriazole part (electron acceptor).

178 Generally, fluorophores comprise D- $\pi$ -A conjugated structures that usually form  
179 TICT states upon light irradiation. BTADA as a D- $\pi$ -A structure molecule has two  
180 kinds of excited states, locally excited (LE) state and TICT state (Fig. 1b). Through  
181 the effect of external conditions, LE state and TICT state can be easily transformed  
182 into each other. When dissolved in low-polar solvent, BTADA is in a coplanar

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183 conformation and the LE state is **the** lowest-energy state. As shown in Fig. 1c, the  
184 cyclohexane solution of BTADA was observed a strong fluorescence emission  
185 wavelength at 449 nm when the excited wavelength is 365 nm. **With the increase of**  
186 **the polarity of the solvent**, the multiple interactions between the electron donor and  
187 acceptor parts of BTADA can enhance the HOMO level and reduce the LOMO level  
188 resulting in a TICT state. **Meanwhile, the fluorescence emission of BTADA has an**  
189 **obvious bathochromic-shift as the polarity of solution increases and BTADA**  
190 **displayed different fluorescene colors from blue to orange in different polarity**  
191 **solvents.** (Fig. 1c and 1e). As shown in Fig. 1d, the polar function ( $\Delta f$ ) of solvents  
192 and the Stokes shift ( $\Delta \nu$ ) shows ideal linear relationships and fitted well with the  
193 Lippert–Mataga plot [43]. These experimental results confirm the TICT property of  
194 BTADA by the solvent polarity dependent fluorescent emission [44].



195

196 **Fig. 1.** (a). Electron structure of BTADA; (b). LE state and TICT state of BTADA; (c).

197 Fluorescence photographs of BTADA in different solvent; (d). Plot of the Stokes shift of

198 BTADA in each solvent versus  $\Delta f$  of the respective solvent. The concentrations of BTADA in

199 the experiments are 50  $\mu\text{M}$ ; (e). Fluorescence images of BTADA in different solvent

### 200 3.2 Aggregation-induced emission effect of BTADA

201 In this part, the fluorescence emission behaviors of BTADA in  $\text{H}_2\text{O}$ -MeOH solution

202 with different water contents ( $f_w$ , the volume percentage of water in  $\text{H}_2\text{O}$ -MeOH

203 solution) were studied. As shown in Fig. 2a and 2b, the yellow fluorescence (550 nm)

204 can be observed under 365 nm as excitation wavelength when BTADA is dissolved in

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205 pure ethanol. The fluorescence of BTADA is slightly bathochromic-shift and  
206 gradually weakens. When water contents are increased from 0 to 70 % in H<sub>2</sub>O-MeOH  
207 solution, which is a sign that the BTADA molecule has turned into a TICT state.  
208 While the  $f_w$  is over 70%, the fluorescence emission intensity is dramatically  
209 increased and fluorescence emission wavelength has obviously blue-shifted into 507  
210 nm under 365 nm as excitation wavelength. In this stage, BTADA molecules are easy  
211 to aggregate due to the hydrophobic interaction. Such aggregation will lead to the  
212 restriction of intramolecular rotations (RIR), thus the non-radioactive channel for  
213 excited state to decay back to ground state are cut off, resulting in Aggregation-  
214 Induced Emission [45]. To further explain the mechanism of the BTADA molecules'  
215 AIE effect, photophysical behaviors of BTADA were studied in the system of  
216 methanol-glycerol mixture as well (Fig. 2c). When the volume percentage of glycerol  
217 in glycerol-MeOH solution ( $f_g$ ) is increased, the viscosity of methanol-glycerol  
218 mixture solution goes up, and so does the fluorescence intensity of BTADA. It  
219 indicates that BTADA is harder and harder to rotate when the viscosity of solution is  
220 gradually increased. This also proves the RIR is the reason for the AIE effect of  
221 BTADA.