Preparation of Aromatic Triazenes and Their Application in Silver-Mediated Perfluoroalkylation Reactions

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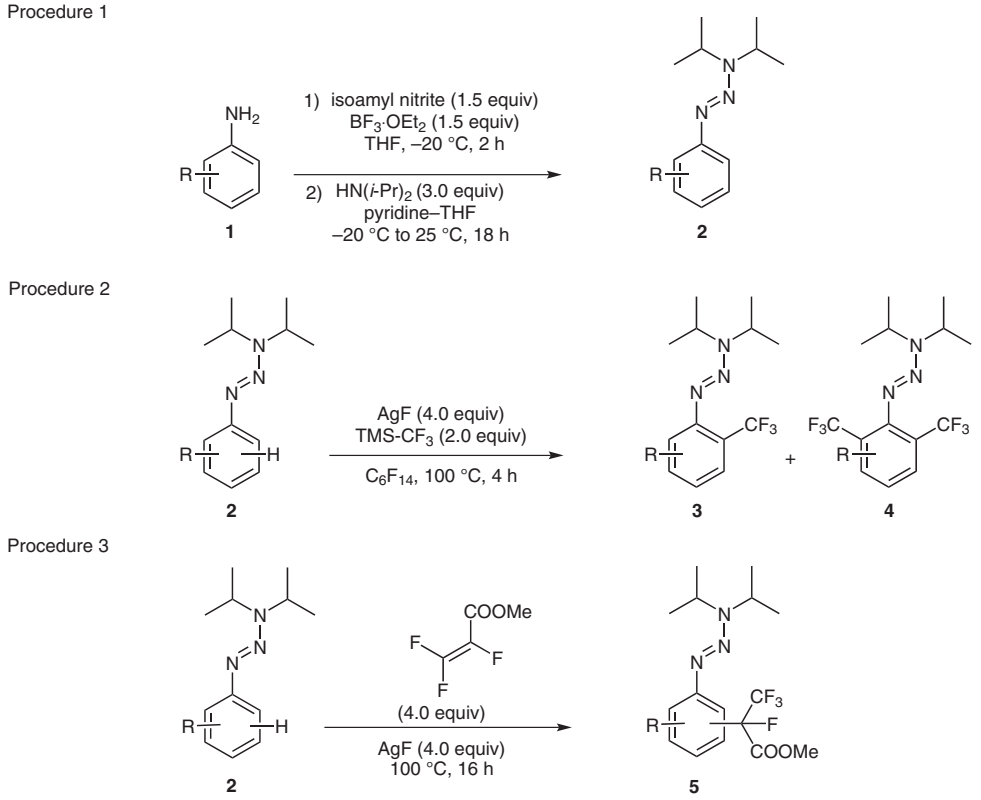
Abstract: Herein, the syntheses of various functionalized 1,3-diisopropyltriaz-1-enes is described. This simple transformation tolerates a vast number of functional groups (e.g., halides) and allows the syntheses of 1,3-diisopropyltriaz-1-enes starting from commercially available aniline derivatives. These substrates are suitable for a range of silver-mediated perfluoroalkylation reactions.

Key words: alkylation, triazene, perfluoroalkylation, silver , synthetic methods



Scheme 1 General procedures for the preparation of functionalized aromatic triazenes and their application in silver-mediated perfluoroalkylation reactions

Introduction

For years, aromatic triazenes have been used as versatile compounds in organic chemistry.[1] Triazenes, which can be regarded as equivalents of protected diazonium salts, offer unique synthetic opportunities due to the fact that they are easily converted into a range of functional groups, which makes them interesting building blocks for chemistry in solution[1b,2] as well as on solid support.[1a,3] In contrast to diazonium salts, aromatic triazenes can be isolated, stored, and are suitable for further transformations on the aromatic core. For example, metal-catalyzed cross-coupling reactions as well as metalation protocols are known.[2b,e] More recently, we have reported a number of silver-mediated perfluoroalkylation reactions of aromatic

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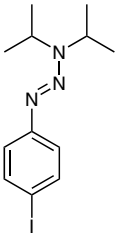
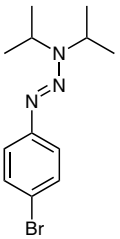
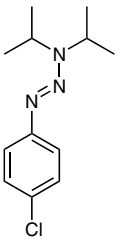
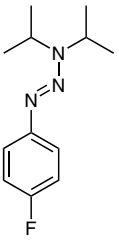
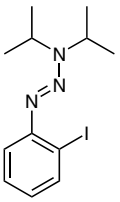
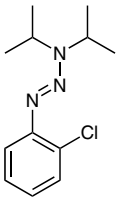
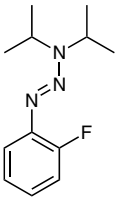
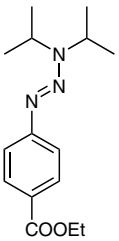
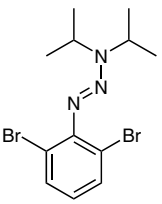
triazenes that proceed through simple CH substitution.[4] These transformations tolerate a broad range of functional groups, which, combined with the versatility of the triazene functionality, make them suitable for the synthesis of a variety of fluorinated aromatic building blocks. Herein, we present an optimized one-step synthesis of a range of functionalized aromatic 1,3-diisopropyltriaz-1-enes and provide new insights into their use in silver-mediated perfluoroalkylation reactions (Scheme 1).

Scope and Limitations

In general, aromatic triazenes can be obtained by two different routes. They can be synthesized from metalated arenes, an azide and an electrophile, or by converting anilines into diazonium salts, which can then be quenched with an amine.[1b] Because various aniline derivatives are commercial available, we focused on the second approach. Starting from functionalized anilines, we first generated the corresponding diazonium salt by using $BF_3{\cdot}OEt_2$ and isoamyl nitrite, which was then reacted with diisopropylamine to give the aromatic triazene.[5] By using this optimized procedure, it was possible to obtain a range of functionalized aromatic triazenes (Table 1) in mostly good to very good yields. It is noteworthy that this procedure could be easily performed on a gram scale. As already mentioned, these triazenes are well-suited as substrates for silver-mediated perfluoroalkylation reactions.

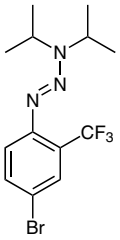
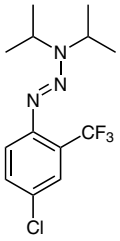
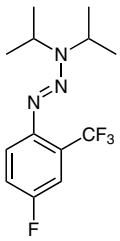
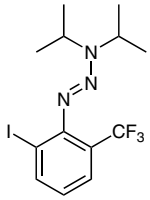
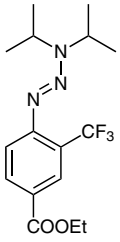
Table 1 Synthesis of Aromatic Triazenes **2** from Commercially Available Aniline Derivatives **1**

Entry	**2**	Triazene	Yield (%)[a]
1	**2a**		74
2	**2b**		76
3	**2c**		71
4	**2d**		77
5	**2e**		77
6	**2f**		94
7	**2g**		92
8	**2h**		44
9	**2i**		71

[a] Isolated yield.

Trifluoromethyl silver organyls can be easily prepared by using (trifluoromethyl)trimethylsilane in the presence of silver(I) fluoride.[6] When heated, these species can be used for the generation of trifluoromethyl radicals, which readily react with aromatic triazenes through simple CH substitution.[4a] We showed that these reactions proceed with high *ortho* selectivity, especially when *para*-substituted aromatic triazenes were used (Table 2). In the case of triazenes **2b**, **2c**, **2d** and **2h**, the corresponding mono-*ortho*-trifluoromethylated and di-*ortho*-trifluoromethylated product could be isolated together in very good yields.

Table 2 Synthesis of Trifluoromethylated Aromatic Triazenes **3** and **4**

Entry	Reactant **2**	Product **3**	Yield (%)[a]
1	**2b**	**3b** 	69 (20)[b]
2	**2c**	**3c** 	67 (24)[b]
3	**2d**	**3d** 	67 (26)[b]
4	**2e**	**3e** 	60 (17)[c]
5	**2h**	**3h** 	53 (19)[b]

[a] Isolated yield.
[b] Isolated yield of the di-*ortho*-trifluoromethylated product **4**.
[c] Isolated yield of the di-*ortho*,*para*-trifluoromethylated product.

When one *ortho* position was blocked by a previously introduced functional group, as in the case of **2e**, the corresponding mono-*ortho*-trifluoromethylated product was still formed as the major product, however the *ortho*,*para*-di-trifluoromethylated byproduct could also be isolated. Furthermore, we could extend this procedure to other perfluoroalkylation reactions such as pentafluoroethylation, heptafluoropropylation, and ethoxycarbonydifluoromethylation, which also showed a high preference for the *ortho*-position.[4b]

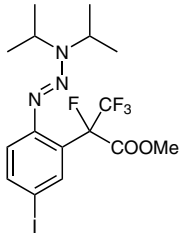
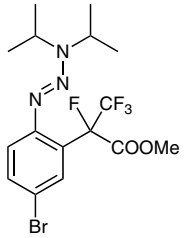
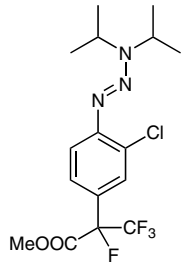
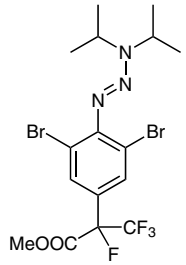
More recently, we demonstrated that highly fluorinated olefins are also useful as perfluoroalkyl sources in this reaction.[4c] By using commercially available methyl 2,3,3-trifluoroacrylate (MTA) as a highly fluorinated olefin, it was possible to synthesize a range of functionalized methoxycarbonyltetrafluoroethylated aromatic triazenes (and anisoles). These reactions could be realized by generation of a perfluoroorgano silver species in situ by nucleophilic regioselective addition of silver(I) fluoride towards the fluorinated double bond of MTA. Herein, it was important to work under solvent-free (neat) conditions because side reactions such as the dimerization or oligomerization of fluorinated olefins in the presence of nucleophiles are suppressed. To the best of our knowledge, this was the first example of the use of highly fluorinated olefins in metal-mediated perfluoroalkylation of aromatic substrates. Based on these results, it was possible to upscale this procedure to >1 mmol scale with comparable yields (Table 3). However, further optimization to enable a simpler setup by using atmospheric conditions instead of an argon atmosphere resulted in reduced yields (Table 3, entry 3). It is noteworthy that all the silver-mediated perfluoroalkylation reactions tolerated a broad range of functional groups including iodides, bromides, chlorides, fluoride, nitriles, and ethoxycarbonyl groups.

Because of the versatile transformation protocols available for the triazene moiety (e.g., transformation into fluorides,[3] iodides,[2e] or azides[2d]), these protocols should find application in the synthesis of a range of fluorinated building blocks.

In summary, we have reported an optimized protocol for the synthesis of a range of functionalized aromatic 1,3-diisopropyltriaz-1-enes. Furthermore, in analogy to our previous work, we showed that these triazenes are suitable substrates for silver-mediated perfluoroalkylation reactions. These reactions, combined with the versatile synthetic nature of the triazene synthon, allow the synthesis of a range of fluorinated building blocks.

All reactions (Table 2, Table 3) were carried out under an argon atmosphere. All starting materials were purchased from commercial suppliers and used without further purification unless otherwise stated. Yields refer to isolated compounds estimated to be >95% pure as determined by ^{1}H NMR spectroscopic analysis. NMR spectra were recorded on a Bruker AM 400, a Bruker Avance 300 or a Bruker DRX 500 spectrometer as solutions. Chemical shifts are expressed in parts per million (ppm, δ) downfield from tetramethylsilane and are referenced to residual solvent peaks. The signal structure in ^{13}C NMR was analyzed by DEPT. Electron impact (EI)

Table 3 Synthesis of Methoxycarbonylated Aromatic Triazenes **5**

Entry	Reactant **2**	Product **4**	Yield (%)[a]
1	**2a**	**4a**  (1.2 mmol)	38
2	**2b**	**4b**  (1.8 mmol)	46
3	**2f**	**4f**  (0.4 mmol)	39[b] (57)[c]
4	**2i**	**4i**  (1.2 mmol)	35

[a] Isolated yield.
[b] Without argon atmosphere, *para*/*ortho* ratio 7.5:1.
[c] Reaction performed under an argon atmosphere.

mass spectrometry was performed by using a Finnigan MAT 95 (70 eV). Infrared spectroscopy (IR) was recorded on a FT-IR Bruker alpha.

Synthesis of Aromatic Triazenes; General Procedure 1 (GP1)
A flask equipped with a septum and a stirring bar was charged with aniline derivative (2.00 g, 1.00 equiv). The flask was closed and THF (5 mL) was added by using a syringe under an argon atmosphere. The solution was cooled to –20 °C and $BF_3{\cdot}OEt_2$ (1.50 equiv) was added. Isoamyl nitrite (1.50 equiv) was then slowly added under vigorous stirring and the solution was stirred for 2 h at this temperature. The precipitate was filtered off and washed with ice-cold Et_2O. Without further isolation, the precipitate was then poured (with MeCN wash) into a freshly a prepared solution containing *i*-Pr_2NH (3.00 equiv) in a mixture of THF–pyridine (9:1, 10 mL) at –20 °C. The solution was stirred and allowed to warm slowly to r.t. for an additional 16 h. The reaction was then quenched with sat. NH_4Cl solution, the aqueous phase was extracted twice with EtOAc and the organic layer was dried over $MgSO_4$. The solvent was removed in vacuum and the crude product was purified by flash column chromatography (silica gel).

Silver-Mediated Trifluoromethylation of Aromatic Triazenes; General Procedure 2 (GP2)
A vial equipped with a septum and a stirring bar was charged with AgF (1.60 mmol) and triazene (0.40 mmol). The reaction vessel was closed, and perfluorohexane (1 mL) was added by using a syringe under an argon atmosphere. TMS-CF_3 (0.80 mmol) was then added and the suspension was heated to 100 °C. The reaction mixture was stirred for 4 h, then the solution was cooled to r.t., EtOAc was added and the solution was stirred for 5 min. The solution was poured into a flask and silica gel was added. Finally, the solvent was removed in vacuum and the crude product was purified by flash column chromatography (silica gel).

Silver-Mediated Methoxycarbonyltetrafluoroethylation of Aromatic Triazenes; General Procedure 3 (GP3)
A vial equipped with a septum and a stirring bar was charged with AgF (4.00 equiv) and triazene (1.00 equiv), the reaction vessel was closed and methyl 2,3,3-trifluoroacrylate (MTA; 4.00 equiv) was added by using a syringe under an argon atmosphere. The suspension was heated to 100 °C and stirred for 16 h at 100 °C. The solution was then cooled to r.t. and EtOAc was added. The solution was poured into a flask and the vial was rinsed a further two times with EtOAc. The solvent was removed from the combined washing under vacuum and the crude product was purified by flash column chromatography (silica gel).

Products of Type 2

(*E*)-1-(4-Iodophenyl)-3,3-diisopropyltriaz-1-ene (2a)
Obtained after flash column chromatography (cyclohexane–EtOAc, 20:1).

Yield: 2.23 g (74%); orange solid; R_f = 0.70 (cyclohexane–EtOAc, 20:1).

IR (film): 3452 (vw), 3074 (vw), 2974 (m), 2931 (w), 2871 (vw), 1893 (vw), 1580 (vw), 1475 (m), 1423 (s), 1404 (m), 1389 (m), 1365 (m), 1298 (w), 1263 (vw), 1262 (s), 1195 (w), 1162 (m), 1100 (w), 1001 (w), 854 (vw), 827 (w), 749 (vw), 662 (vw), 577 (vw), 535 (vw), 470 (vw) cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 1.31 (br s, 12 H, CH_3), 4.00 (br s, 1 H, CH), 5.27 (br s, 1 H, CH), 7.18 (d, ^3J = 8.6 Hz, 2 H, Ar-H-2, Ar-H-6), 7.62 (d, ^3J = 8.6 Hz, 2 H, Ar-H-3, Ar-H-5).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 19.3 (+, br s, CH_3), 23.8 (+, br s, CH_3), 46.0 (+, br s, CH), 48.8 (+, br s, CH), 88.4 (C_{quat}, C-4), 122.3 (+, CH-2, CH-6), 137.6 (+, CH-3, CH-5), 151.4 (C_{quat}, C-1).

MS (70 eV, EI): *m*/*z* (%) = 331 (32) [M^+], 231 (40) [M^+–$C_6H_{14}N$], 203 (100) [M^+–$C_6H_{14}N_3$].

HRMS (EI): *m*/*z* [M^+] calcd for $C_{12}H_{18}IN_3$: 331.0545; found: 331.0544.

(*E*)-1-(4-Bromophenyl)-3,3-diisopropyltriaz-1-ene (2b)
Obtained after flash column chromatography (cyclohexane–EtOAc, 10:1).

Yield: 2.53 g (76%); red oil; R_f = 0.25 (cyclohexane–EtOAc, 10:1).

IR (film): 3448 (vw), 2975 (m), 2932 (vw), 2871 (vw), 1893 (vw), 1585 (vw), 1478 (vw), 1425 (m), 1404 (m), 1366 (m), 1296 (w), 1194 (w), 1161 (m), 1128 (w), 1099 (w), 1067 (w), 1031 (w), 1004 (w), 914 (vw), 855 (vw), 829 (w), 705 (vw), 670 (vw), 578 (vw), 554 (vw), 534 (vw), 474 (vw), 427 (vw) cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 1.31 (br s, 12 H, CH_3), 4.00 (br s, 1 H, CH), 5.26 (br s, 1 H, CH), 7.28 (d, ^3J = 8.6 Hz, 2 H, Ar-H-2, Ar-H-6), 7.41 (d, ^3J = 8.6 Hz, 2 H, Ar-H-3, Ar-H-5).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 19.5 (+, br s, CH_3), 23.8 (+, br s, CH_3), 46.0 (+, br s, CH), 48.9 (+, br s, CH), 117.6 (C_{quat}, C-4), 121.8 (+, CH-2, CH-6), 131.7 (+, CH-3, CH-5), 150.8 (C_{quat}, C-1).

MS (70 eV, EI): *m*/*z* (%) = 283 (24) [M^+], 183 (38) [$M^+ - C_6H_{14}N$], 155 (100) [$M^+ - C_6H_{14}N_3$].

HRMS (EI): *m*/*z* [M^+] calcd for $C_{12}H_{18}BrN_3$: 283.0684; found: 283.0683.

(*E*)-1-(4-Chlorophenyl)-3,3-diisopropyltriaz-1-ene (2c)
Obtained after flash column chromatography (cyclohexane–EtOAc, 10:1).

Yield: 2.66 g (71%); red oil; R_f = 0.57 (cyclohexane–EtOAc, 10:1).

IR (film): 2976 (s), 2933 (m), 2872 (w), 1892 (vw), 1647 (vw), 1483 (s), 1428 (s), 1401 (s), 1366 (s), 1297 (m), 1228 (vs), 1194 (m), 1161 (s), 1128 (m), 1088 (s), 1032 (m), 1008 (w), 915 (vw), 855 (vw), 833 (s), 708 (vw), 687 (vw), 633 (vw), 579 (vw), 565 (vw), 535 (w), 486 (w) cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.23 (br s, 12 H, CH_3), 3.93 (br s, 1 H, CH), 5.19 (br s, 1 H, CH), 7.18–7.20 (m, 2 H, Ar-H-3, Ar-H-5), 7.25–7.28 (m, 2 H, Ar-H-2, Ar-H-6).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 19.5 (+, br s, CH_3), 23.8 (+, br s, CH_3), 46.2 (+, br s, CH), 48.9 (+, br s, CH), 121.4 (+, CH-3, CH-5), 128.7 (+, CH-2, CH-6), 129.7 (C_{quat}, C-4), 150.3 (C_{quat}, C-1).

MS (70 eV, EI): *m*/*z* (%) = 239 (35) [M^+], 139 (39) [$M^+ - C_6H_{14}N$], 111 (100) [$M^+ - C_6H_{14}N_3$].

HRMS (EI): *m*/*z* [M^+] calcd for $C_{12}H_{18}ClN_3$: 239.1189; found: 239.1187.

(*E*)-1-(4-fluorophenyl)-3,3-diisopropyltriaz-1-ene (2d)
Obtained after flash column chromatography (cyclohexane–EtOAc, 10:1).

Yield: 3.08 g (77%); red oil; R_f = 0.67 (cyclohexane–EtOAc, 10:1).

IR (film): 3443 (vw), 2975 (w), 2934 (w), 1594 (vw), 1499 (m), 1468 (w), 1435 (m), 1405 (m), 1366 (w), 1297 (w), 1265 (w), 1215 (m), 1187 (w), 1142 (w), 1098 (w), 1032 (w), 915 (vw), 589 (vw), 838 (w), 804 (vw), 732 (vw), 639 (vw), 602 (vw), 537 (vw), 519 (vw), 408 (vw) cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.23 (br s, 12 H, CH_3), 4.02 (br s, 1 H, CH), 5.07 (br s, 1 H, CH), 6.90–6.95 (m, 2 H, Ar-H-3, Ar-H-5), 7.28–7.32 (m, 2 H, Ar-H-2, Ar-H-6).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 22.0 (+, br s, CH_3), 47.7 (+, br s, CH), 115.3 (+, d, ^2J = 22.1 Hz, CH-3, CH-5), 121.3 (+, d, ^3J = 8.0 Hz, CH-2, CH-6), 148.1 (C_{quat}, d, ^4J = 2.9 Hz, C-1), 160.4 (C_{quat}, ^2J = 242.4 Hz, C-4).

MS (70 eV, EI): *m*/*z* (%) = 223 (26) [M^+], 123 (41) [$M^+ - C_6H_{14}N$], 100 (12) [C_6H_4N], 95 (100) [$M^+ - C_6H_{14}N_3$].

HRMS (EI): *m*/*z* [M^+] calcd for $C_{12}H_{18}FN_3$: 223.1484; found: 223.1483.

(*E*)-1-(2-Iodophenyl)-3,3-diisopropyltriaz-1-ene (2e)
Obtained after flash column chromatography (cyclohexane–EtOAc, 10:1).

Yield: 2.34 g (77%); orange solid; R_f = 0.53 (cyclohexane–EtOAc, 10:1).

IR (ATR): 3059 (vw), 2970 (w), 2929 (vw), 1575 (vw), 1458 (w), 1435 (vw), 1397 (m), 1365 (m), 1285 (vw), 1256 (m), 1221 (m), 1192 (m), 1148 (m), 1128 (m), 1111 (w), 1092 (m), 1042 (vw), 1027 (m), 1010 (m), 852 (vw), 762 (w), 742 (m), 712 (w), 661 (vw), 626 (w), 582 (vw), 541 (m), 517 (w), 439 (vw), 411 (vw) cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.34 (br s, 6 H, CH_3), 1.39 (br s, 6 H, CH_3), 4.04 (br s, 1 H, CH), 5.19 (br s, 1 H, CH), 6.82 (ddd, ^3J = 7.8 Hz, ^3J = 7.1 Hz, ^4J = 1.6 Hz, 1 H, Ar-H-4), 7.27 (ddd, ^3J = 8.1 Hz, ^3J = 7.1 Hz, ^4J = 1.4 Hz, 1 H, Ar-H-5), 7.36 (dd, ^3J = 8.1 Hz, ^4J = 1.6 Hz, 1 H, Ar-H-6), 7.84 (dd, ^3J = 7.8 Hz, ^4J = 1.4 Hz, 1 H, Ar-H-3).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 19.1 (+, CH_3), 23.8 (+, CH_3), 47.6 (+, CH), 49.8 (+, CH), 96.7 (C_{quat}, C-2), 117.3 (+, CH-6), 126.1 (+, CH-4), 128.5 (+, CH-5), 139.0 (+, CH-3), 150.8 (C_{quat}, C-1).

MS (70 eV, EI): *m*/*z* (%) = 331 (35) [M^+], 231 (26) [$M^+ - C_6H_{14}N$], 203 (100) [$M^+ - C_6H_{14}N_3$].

HRMS (EI): *m*/*z* [M^+] calcd for $C_{12}H_{18}IN_3$: 331.0545; found: 331.0544.

(*E*)-1-(2-Chlorophenyl)-3,3-diisopropyltriaz-1-ene (2f)
Obtained after flash column chromatography (cyclohexane–EtOAc, 25:1).

Yield: 3.55 g (94%); red solid; R_f = 0.50 (cyclohexane–EtOAc, 20:1).

IR (ATR): 3067 (vw), 2974 (w), 2931 (w), 1582 (vw), 1467 (w), 1399 (s), 1368 (m), 1291 (w), 1261 (m), 1222 (m), 1195 (m), 1150 (m), 1128 (m), 1095 (m), 1055 (m), 1030 (m), 912 (w), 858 (w), 768 (m), 740 (m), 719 (w), 693 (w), 631 (w), 584 (w), 549 (m), 522 (m), 457 (w), 429 (w) cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.33–1.34 (m, 12 H, CH_3), 4.04 (br s, 1 H, CH), 5.23 (br s, 1 H, CH), 7.02–7.06 (m, 1 H, Ar-H-5), 7.19–7.23 (m, 1 H, Ar-H-4), 7.39–7.41 (m, 1 H, Ar-H-6), 7.44–7.47 (m, 1 H, Ar-H-3).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 19.0 (+, CH_3), 23.7 (+, CH_3), 47.0 (+, CH), 49.7 (+, CH), 118.2 (+, CH-6), 125.2 (+, CH-4), 126.9 (+, CH-5), 129.1 (C_{quat}, C-2), 129.9 (+, CH-3), 147.9 (C_{quat}, C-1).

MS (EI): *m*/*z* (%) = 241/239 (9/22) [M^+], 141/139 (9/52) [$M^+ - C_6H_{14}N$], 113/111 (45/100) [$M^+ - C_6H_{14}N_3$], 100 (63) [$C_6H_{14}N$].

HRMS (EI): *m*/*z* [M^+] calcd for $C_{12}H_{18}ClN_3$: 239.1189; found: 239.1188.

(*E*)-1-(2-Fluorophenyl)-3,3-diisopropyltriaz-1-ene (2g)
Obtained after flash column chromatography (cyclohexane–EtOAc, 25:1).

Yield: 3.70 g (92%); orange solid; R_f = 0.63 (cyclohexane–EtOAc, 25:1).

IR (ATR): 2976 (w), 2934 (w), 2872 (vw), 1582 (w), 1486 (m), 1454 (w), 1399 (m), 1369 (m), 1268 (m), 1233 (m), 1209 (m), 1182 (w), 1148 (m), 1103 (m), 1028 (m), 933 (w), 915 (w), 888 (w), 854 (vw), 817 (m), 748 (m), 731 (m), 632 (w), 589 (w), 564 (w), 529 (w), 504 (w), 471 (w), 426 (vw) cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.20–1.45 (m, 12 H, CH_3), 4.02 (br s, 1 H, CH), 5.33 (br s, 1 H, CH), 7.01–7.12 (m, 3 H, Ar-H), 7.42–7.49 (m, 1 H, Ar-H-3).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 19.3 (+, CH_3), 23.9 (+, CH_3), 46.1 (+, CH), 49.0 (+, CH), 116.1 (+, d, ^2J = 20.0 Hz, CH-3), 119.0 (+, d, ^4J = 2.0 Hz, CH-5), 123.9 (+, d, ^3J = 3.7 Hz, CH-6), 125.2 (+, d, ^3J = 7.7 Hz, CH-4), 139.8 (C_{quat}, d, ^2J = 7.4 Hz, C-1), 156.3 (C_{quat}, d, ^1J = 248.5 Hz, C-2).

^{19}F NMR (367 MHz, $CDCl_3$): δ = –128.59 (s, 1 F, Ar-F).

MS (EI): *m*/*z* (%) = 223 (23) [M^+], 123 (68) [$M^+ - C_6H_{14}N$], 100 (22) [$C_6H_{14}N$], 95 (100) [$M^+ - C_6H_{14}N_3$].

HRMS (EI): *m*/*z* [M^+] calcd for $C_{12}H_{18}FN_3$: 223.1485; found: 223.1485.

(*E*)-1-(4-Ethoxycarbonylphenyl)-3,3-diisopropyltriaz-1-ene (2h)
Obtained after flash column chromatography (cyclohexane–EtOAc, 10:1).

Yield: 1.49 g (44%); light-yellow solid; R_f = 0.40 (cyclohexane–EtOAc, 10:1).

IR (ATR): 2972 (w), 1707 (m), 1601 (m), 1459 (w), 1409 (m), 1390 (m), 1365 (m), 1311 (w), 1266 (m), 1249 (m), 1225 (m), 1154 (m),

1129 (m), 1096 (m), 1026 (m), 916 (w), 860 (m), 775 (m), 748 (w), 700 (m), 579 (w), 558 (m), 540 (m), 440 (w) cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 1.26 (br s, 6 H, CH_3), 1.38 (t, ^3J = 7.1 Hz, 3 H, CH_2CH_3), 1.39 (br s, 6 H, CH_3), 4.02 (br s, 1 H, CH), 4.35 (q, ^3J = 7.1 Hz, 2 H, CH_2), 5.34 (br s, 1 H, CH), 7.43 (d, ^3J = 8.7 Hz, 2 H, Ar-H-2, Ar-H-6), 8.00 (d, ^3J = 8.7 Hz, 2 H, Ar-H-3, Ar-H-5).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 14.4 (+, CH_3), 19.3 (+, br s, CH_3), 23.9 (+, br s, CH_3), 46.3 (+, CH), 49.2 (+, CH), 60.5 (–, CH_2), 119.8 (+, CH-2, CH-6), 126.2 (C_{quat}, C-4), 130.5 (+, CH-3, CH-5), 155.3 (C_{quat}, C-1), 166.8 (C_{quat}, CO).

MS (70 eV, EI): *m*/*z* (%) = 277 (37) [M^+], 177 (16) [$M^+ – C_6H_{14}N$], 149 (100) [$M^+ – C_6H_{14}N_3$].

HRMS (EI): *m*/*z* [M^+] calcd for $C_{15}H_{23}O_2N_3$: 277.1790; found: 277.1793.

(*E*)-1-(2,6-Bisbromophenyl)-3,3-diisopropyltriaz-1-ene (2i)
Obtained after flash column chromatography (cyclohexane–EtOAc, 10:1).

Yield: 2.06 g (71%); beige solid; R_f = 0.82 (cyclohexane–EtOAc, 10:1).

IR (ATR): 2969 (w), 2928 (w), 1545 (w), 1467 (w), 1397 (m), 1360 (m), 1270 (m), 1225 (m), 1191 (m), 1157 (m), 1130 (m), 1096 (w), 1066 (w), 1028 (m), 783 (m), 766 (m), 713 (m), 655 (w), 585 (w), 546 (w), 519 (m) cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 1.33 (d, ^3J = 6.8 Hz, 6 H, CH_3), 1.37 (d, ^3J = 6.6 Hz, 6 H, CH_3), 4.04 (sept, ^3J = 6.6 Hz, 1 H, CH), 5.15 (sept, ^3J = 6.8 Hz, 1 H, CH), 6.83 (t, ^3J = 8.0 Hz, 1 H, Ar-H-4), 7.52 (d, ^3J = 8.0 Hz, 2 H, Ar-H-3, Ar-H-5).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 19.1 (+, CH_3), 23.7 (+, CH_3), 46.7 (+, CH), 49.7 (+, CH), 118.1 (C_{quat}, C-2, C-6), 126.2 (+, CH-4), 132.2 (+, CH-3, CH-5), 148.9 (C_{quat}, C-1).

MS (70 eV, EI): *m*/*z* (%) = 363 (24) [M^+], 263 (40) [$M^+ – C_6H_{14}N$], 235 (63) [$M^+ – C_6H_{14}N_3$], 100 (100) [$C_6H_{14}N$].

HRMS (EI): *m*/*z* [M^+] calcd for $C_{12}H_{17}Br_2N_3$: 360.9789; found: 360.9792.

Products of Type 3

(*E*)-1-[4-Bromo-2-(trifluoromethyl)phenyl]-3,3-diisopropyltriaz-1-ene (3b)
Obtained after flash column chromatography (cyclohexane).

Yield: 97 mg (69%); yellow oil; R_f = 0.47 (cyclohexane). Analytical data were identical with those reported.[4a]

(*E*)-1-[4-Chloro-2-(trifluoromethyl)phenyl]-3,3-diisopropyltriaz-1-ene (3c)
Obtained after flash column chromatography (cyclohexane).

Yield: 82 mg (67%); yellow oil; R_f = 0.40 (cyclohexane). Analytical data were identical with those reported.[4a]

(*E*)-1-[4-Fluoro-2-(trifluoromethyl)phenyl]-3,3-diisopropyltriaz-1-ene (3d)
Obtained after flash column chromatography (cyclohexane).

Yield: 78 mg (67%); slightly yellow oil; R_f = 0.49 (cyclohexane). Analytical data were identical with those reported.[4a]

(*E*)-1-[2-Iodo-6-(trifluoromethyl)phenyl]-3,3-diisopropyltriaz-1-ene (3e)
Obtained after flash column chromatography (cyclohexane).

Yield: 96 mg (60%); yellow oil; R_f = 0.10 (cyclohexane). Analytical data were identical with those reported.[4a]

(*E*)-1-[4-Ethoxycarbonyl-2-(trifluoromethyl)phenyl]-3,3-diisopropyltriaz-1-ene (3h)
Obtained after flash column chromatography (pentane to pentane–Et_2O, 50:1).

Yield: 73 mg (53%); yellow oil; R_f = 0.19 (cyclohexane–EtOAc, 50:1). Analytical data were identical with those reported.[4a]

Products of Type 4

(*E*)-1-[4-Bromo-2,6-(bistrifluoromethyl)phenyl]-3,3-diisopropyltriaz-1-ene (4b)
Obtained after flash column chromatography (cyclohexane).

Yield: 33 mg (20%); yellow oil; R_f = 0.29 (cyclohexane).

IR (film): 3443 (vw), 3091 (vw), 2978 (w), 2936 (w), 1580 (w), 1412 (m), 1385 (w), 1369 (m), 1333 (m), 1294 (m), 1257 (m), 1233 (m), 1188 (m), 1146 (m), 1072 (w), 1032 (w), 893 (w), 861 (vw), 838 (w), 812 (vw), 769 (w), 695 (w), 680 (w), 654 (vw), 594 (vw), 542 (vw), 508 (vw) cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 1.27 (d, ^3J = 6.8 Hz, 6 H, CH_3), 1.31 (d, ^3J = 6.6 Hz, 6 H, CH_3), 4.02 (sept, ^3J = 6.6 Hz, 1 H, CH), 5.13 (sept, ^3J = 6.8 Hz, 1 H, CH), 7.92 (s, 2 H, Ar-H-3, Ar-H-5).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 19.0 (+, CH_3), 23.0 (+, CH_3), 47.0 (+, CH), 50.0 (+, CH), 116.1 (C_{quat}, CBr), 122.7 (C_{quat}, q, ^1J = 274.2 Hz, CF_3), 125.9 (C_{quat}, q, ^2J = 31.3 Hz, C-2, C-6), 133.2 (+, q, ^3J = 5.7 Hz, CH-3, CH-5), 149.9 (C_{quat}, C-1).

^{19}F NMR (367 MHz, $CDCl_3$): δ = –58.8 (s, 6 F, CF_3).

MS (70 eV, EI): *m*/*z* (%) = 419 (36) [M^+], 319 (24) [$M^+ – C_6H_{14}N$], 291 (95) [$M^+ – C_6H_{14}N_3$], 100 (100) [$C_6H_{14}N$].

HRMS (EI): *m*/*z* [M^+] calcd for $C_{14}H_{16}BrN_3F_6$: 419.0431; found: 419.0434.

(*E*)-1-[4-Chloro-2,6-(bistrifluoromethyl)phenyl]-3,3-diisopropyltriaz-1-ene (4c)
Obtained after flash column chromatography (cyclohexane).

Yield: 36 mg (24%); yellow oil; R_f = 0.17 (cyclohexane).

IR (film): 2977 (w), 1580 (vw), 1405 (s), 1367 (m), 1335 (w), 1293 (m), 1253 (m), 1230 (m), 1185 (s), 1135 (s), 1072 (m), 1031 (m), 893 (m), 864 (w), 841 (w), 773 (w), 707 (w), 681 (m), 657 (w), 601 (w), 545 (w), 511 (w), 477 (w) cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 1.28 (d, ^3J = 6.8 Hz, 6 H, CH_3), 1.31 (d, ^3J = 6.6 Hz, 6 H, CH_3), 4.02 (sept, ^3J = 6.6 Hz, 1 H, CH), 5.13 (sept, ^3J = 6.8 Hz, 1 H, CH), 7.78 (s, 2 H, Ar-H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 19.0 (+, CH_3), 23.0 (+, CH_3), 47.0 (+, CH), 50.0 (+, CH), 122.8 (C_{quat}, q, ^1J = 274.1 Hz, CF_3), 125.6 (C_{quat}, q, ^2J = 31.3 Hz, C-2, C-6), 129.0 (C_{quat}, CBr), 130.3 (+, q, ^3J = 5.5 Hz, CH-3, CH-5), 149.5 (C_{quat}, C-1).

^{19}F NMR (367 MHz, $CDCl_3$): δ = –58.9 (s, 6 F, CF_3).

MS (70 eV, EI): *m*/*z* (%) = 375 (60) [M^+], 275 (13) [$M^+ – C_6H_{14}N$], 247 (24) [$M^+ – C_6H_{14}N_3$], 100 (100) [$C_6H_{14}N$].

HRMS (EI): *m*/*z* [M^+] calcd for $C_{14}H_{16}ClN_3F_6$: 375.0937; found: 375.0939.

(*E*)-1-[4-Fluoro-2,6-(bistrifluoromethyl)phenyl]-3,3-diisopropyltriaz-1-ene (4d)
Obtained after flash column chromatography (cyclohexane).

Yield: 38 mg (26%); yellow oil; R_f = 0.23 (cyclohexane).

IR (film): 2977 (w), 1599 (vw), 1462 (m), 1408 (m), 1362 (m), 1297 (m), 1279 (w), 1244 (m), 1183 (m), 1135 (s), 1065 (w), 1031 (m), 949 (m), 887 (m), 836 (w), 780 (w), 727 (w), 688 (w), 662 (w), 619 (w), 551 (w), 520 (w), 430 (w) cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 1.26 (d, ^3J = 6.8 Hz, 6 H, CH_3), 1.31 (d, ^3J = 6.6 Hz, 6 H, CH_3), 4.01 (sept, ^3J = 6.6 Hz, 1 H, CH), 5.13 (sept, ^3J = 6.8 Hz, 1 H, CH), 7.53 (d, ^1J = 8.4 Hz, 1 H, Ar-H-6).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 19.0 (+, CH_3), 23.0 (+, CH_3), 46.8 (+, CH), 49.9 (+, CH), 117.5 (+, dq, ^2J = 25.0 Hz, ^3J = 5.6 Hz, CH-3, CH-5), 122.6 (C_{quat}, dq, ^1J = 273.9 Hz, ^4J = 2.4 Hz, CF_3), 125.8

(C_{quat}, dq, ^2J = 31.6 Hz, ^3J = 7.2 Hz, C-2, C-6), 147.4 (C_{quat}, C-1), 157.9 (C_{quat}, d, ^1J = 245.4 Hz, C-4).

^{19}F NMR (367 MHz, $CDCl_3$): δ = –58.9 (s, 6 F, CF_3), –116.7 (s, 1 F, CF).

MS (70 eV, EI): *m*/*z* (%) = 359 (49) [M^+], 259 (16) [$M^+ - C_6H_{14}N$], 231 (38) [$M^+ - C_6H_{14}N_3$], 100 (100) [$C_6H_{14}N$].

HRMS (EI): *m*/*z* [M^+] calcd for $C_{14}H_{16}N_3F_7$: 359.1232; found: 359.1229.

(*E*)-1-[2-Iodo-4,6-(trifluoromethyl)phenyl]-3,3-diisopropyltriaz-1-ene (4e)
Obtained after flash column chromatography (cyclohexane).

Yield: 32 mg (17%); yellow oil; R_f = 0.18 (cyclohexane).

IR (film): 2978 (m), 2936 (w), 1612 (w), 1468 (w), 1413 (m), 1384 (w), 1368 (m), 1332 (m), 1282 (m), 1266 (m), 1232 (m), 1210 (m), 1137 (s), 1094 (m), 1068 (w), 1030 (w), 900 (w), 866 (vw), 783 (vw), 764 (vw), 690 (w), 677 (w), 665 (vw), 544 (vw), 430 (vw) cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.33 (d, ^3J = 6.8 Hz, 6 H, CH_3), 1.37 (d, ^3J = 6.6 Hz, 6 H, CH_3), 4.07 (sept, ^3J = 6.6 Hz, 1 H, CH), 5.18 (sept, ^3J = 6.8 Hz, 1 H, CH), 7.87 (s, 1 H, Ar-H-5), 8.25 (s, 1 H, Ar-H-3).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 19.1 (+, CH_3), 23.4 (+, CH_3), 47.4 (+, CH), 50.2 (+, CH), 94.3 (C_{quat}, C-2), 122.7 (C_{quat}, q, ^1J = 272.4 Hz, CF_3), 122.74 (C_{quat}, q, ^1J = 274.1 Hz, CF_3), 124.1–124.4 (+, m, CH-5), 123.2 (C_{quat}, q, ^2J = 31.5 Hz, C-6), 127.4 (C_{quat}, q, ^2J = 33.7 Hz, C-4), 139.54 (+, q, ^3J = 3.5 Hz, CH-3), 154.8 (C_{quat}, C-1).

^{19}F NMR (367 MHz, $CDCl_3$): δ = –59.2 (s, 3 F, CF_3-6), –62.2 (s, 3 F, CF_3-4).

MS (70 eV, EI): *m*/*z* (%) = 467 (48) [M^+], 367 (17) [$M^+ - C_6H_{14}N$], 339 (58) [$M^+ - C_6H_{14}N_3$], 212 (32) [$M^+ - C_6H_{14}IN_3$], 58 (100).

HRMS (EI): *m*/*z* [M^+] calcd for $C_{14}H_{16}IN_3F_6$: 467.0293; found: 467.0291.

(*E*)-1-[4-Ethoxycarbonyl-2,6-(bistrifluoromethyl)phenyl]-3,3-diisopropyltriaz-1-ene (4h)
Obtained after flash column chromatography (pentane to pentane–Et_2O, 50:1).

Yield: 32 mg (19%); slightly yellow oil; R_f = 0.30 (cyclohexane–EtOAc, 50:1).

IR (film): 3439 (vw), 2980 (w), 2938 (w), 1727 (m), 1618 (m), 1581 (w), 1465 (w), 1415 (m), 1368 (m), 1308 (m), 1249 (m), 1191 (m), 1141 (m), 1099 (m), 1074 (m), 1030 (m), 930 (w), 885 (w), 858 (w), 835 (w), 768 (w), 693 (vw), 681 (w), 665 (vw), 595 (vw), 496 (vw) cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.29 (d, ^3J = 6.8 Hz, 6 H, CH_3), 1.34 (d, ^3J = 6.6 Hz, 6 H, CH_3), 1.42 (t, ^3J = 7.1 Hz, 3 H, CH_2CH_3), 4.05 (sept, ^3J = 6.6 Hz, 1 H, CH), 4.42 (q, ^3J = 7.1 Hz, 2 H, CH_2CH_3), 5.16 (sept, ^3J = 6.8 Hz, 1 H, CH), 8.47 (s, 2 H, Ar-H-3, Ar-H-5).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 14.3 (+, CH_3), 19.0 (+, CH_3), 23.0 (+, CH_3), 47.4 (+, CH), 50.4 (+, CH), 61.6 (–, CH_2), 123.3 (C_{quat}, q, ^1J = 273.8 Hz, CF_3), 124.3 (C_{quat}, q, ^2J = 31.3 Hz, C-2, C-6), 125.6 (C_{quat}, C-4), 131.6 (+, q, ^3J = 5.5 Hz, CH-3, CH-5), 154.2 (C_{quat}, C-1), 164.6 (C_{quat}, CO).

^{19}F NMR (367 MHz, $CDCl_3$): δ = –58.8 (s, 6 F, CF_3).

MS (70 eV, EI): *m*/*z* (%) = 413 (100) [M^+], 313 (36) [$M^+ - C_6H_{14}N$], 285 (84) [$M^+ - C_6H_{14}N_3$].

HRMS (EI): *m*/*z* [M^+] calcd for $C_{17}H_{21}O_2N_3F_6$: 413.1538; found: 413.1540.

Products of Type 5

(*E*)-Methyl 2-[2-(3,3-Diisopropyltriaz-1-en-1-yl)-5-iodophenyl]-2,3,3,3-tetrafluoropropanoate (5a)
The reaction was conducted on 1.2 mmol scale and the product was obtained after flash column chromatography (cyclohexane–EtOAc, 50:1).

Yield: 221 mg (38%); yellow solid; R_f = 0.18 (cyclohexane–EtOAc, 50:1). Analytical data were identical with those reported.[4c]

(*E*)-Methyl 2-[5-Bromo-2-(3,3-diisopropyltriaz-1-en-1-yl)phenyl]-2,3,3,3-tetrafluoropropanoate (5b)
The reaction was conducted on 1.8 mmol scale and the product was obtained after flash column chromatography (cyclohexane–EtOAc, 20:1).

Yield: 363 mg (46%); orange solid; R_f = 0.25 (cyclohexane–EtOAc, 20:1). Analytical data were identical with those reported.[4c]

(*E*)-Methyl 2-[3-Chloro-4-(3,3-diisopropyltriaz-1-en-1-yl)phenyl]-2,3,3,3-tetrafluoropropanoate (5f)
The reaction was conducted on 0.4 mmol scale according to GP3 but under atmospheric conditions instead of under an argon atmosphere. The product was obtained as a 7.5:1 mixture of *para*- and *ortho*-methoxycarbonyltetrafluoroethylated product after flash column chromatography (cyclohexane–EtOAc, 50:1).

Yield: 61 mg (39%); yellow oil; R_f = 0.15 (cyclohexane–EtOAc, 50:1). Analytical data were identical with those reported.[4c]

(*E*)-Methyl 2-[3,5-Dibromo-4-(3,3-diisopropyltriaz-1-en-1-yl)phenyl]-2,3,3,3-tetrafluoropropanoate (5i)
The reaction was conducted on 1.2 mmol scale and the product was obtained after flash column chromatography (cyclohexane–EtOAc, 50:1).

Yield: 220 mg (35%); white solid; R_f = 0.30 (cyclohexane–EtOAc, 50:1). Analytical data were identical with those reported.[4c]

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