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Synthesis and Insecticidal Activities of Novel Analogues of Flubendiamide Containing a Hexafluoroisopropanol Moiety†

Wu, Mingxi(吴明熹) Zhao, Wenwen(赵雯雯) Jin, Guanyi(金观毅)
Huang, Qingchun(黄青春) Cao, Song*(曹松)

Shanghai Key Laboratory of Chemical Biology, School of Pharmacy, East China University of Science and Technology, Shanghai 200237, China

Ten novel analogues of flubendiamide containing a hexafluoroisopropanol moiety were designed and synthesized. Their insecticidal activities against armyworm (*Pseudaletia separata* Walker) were examined and compared with the commercial product flubendiamide. Compound **7b** showed nearly the same insecticidal activity as flubendiamide against armyworm.

Keywords hexafluoroisopropanol moiety, flubendiamide, synthesis, insecticidal activities

Introduction

Ryanodine is an ester of the alcohol (ryanodol) (Figure 1, left), a poisonous alkaloid derived from the South American plant known as *Ryania speciosa* (Flacourtiaceae). It was originally used as an insecticide. Ryanodine can disrupt calcium channels of insects, modify the calcium storage of muscles and cause uncontrollable muscle spasms.[1] However, attempts to develop Ryanodine as a commercial insecticide have not proven successful. The cost and mammalian toxicity associated with Ryanodine limit their agricultural use. Moreover, no commercial synthetic routes of Ryanodine or its derivatives have been found so far. In 2007, Bayer CropScience and Nihon Nohyaku launched flubendiamide (Figure 1, right), a new insecticide with a novel mode of action for controlling lepidopterous pests.[2] It disrupts the proper muscle function in insects and therefore is considered as the first synthetic classes of potent activators of insect ryanodine receptors.[3]

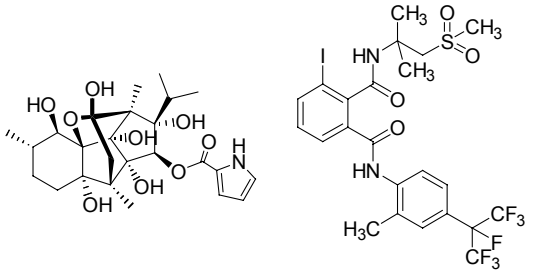

Figure 1 Structure of Ryanodine (left) and flubendiamide (right).

Since the first commercial phthalic diamide, flubendiamide, was widely used in the world in 2007, there have been numerous reports and researches on the optimization of flubendiamide.[4] These studies have focused on the modification of the phthaloyl moiety, the heptafluoroisopropyl group in the anilide moiety, and the sulfonylalkyl group in the aliphatic amide moiety.[5] Although flubendiamide exhibits excellent activities against various insects, the use of expensive starting material (heptafluoroisopropyl iodide) and the difficult handling and storing of this reagent have posed a few problems for their further development. Furthermore, the method of the synthesis of the key intermediates, heptafluoroisopropyl anilines, is protected by patents. Thus, it is highly desirable to replace heptafluoroisopropyl group by other fluorine-containing groups.[6]

It is well-known that the incorporation of fluorine-containing group to alter the chemical, physical, and biological properties of the parent compounds has found many applications in pharmaceutical chemistry, materials and agricultural industries.[7] Different fluorine-containing groups surely have different effects on the molecules. Hexafluoroisopropanol moiety attracts much attention in materials chemistry due to its dissolution behavior, anti-swelling property, and high contrast.[8] However, only a few examples of the synthesis and bioassay of hexafluoroisopropanol unit-containing compounds have been reported.[9] For example, compound **I** is a synthetic agonist for the orphan nuclear receptors RORα and RORγ.[10] It was found that in compound **II**, the hexafluorocarbinol moiety is essential for activation of the LXRα receptor.[11]

* E-mail: scao@ecust.edu.cn; Tel.: 0086-021-64253452; Fax: 0086-021-64252603
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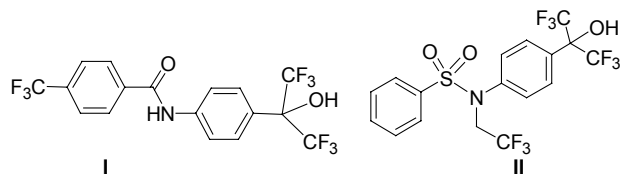
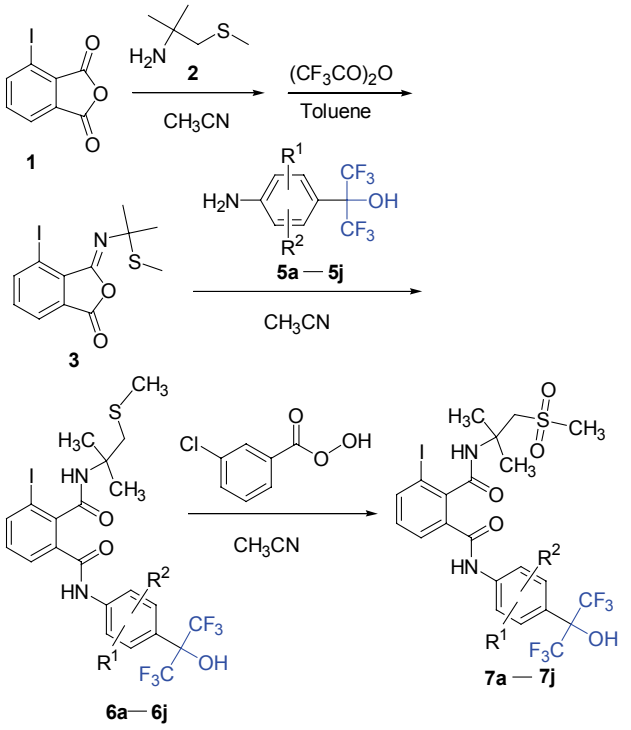


Figure 2 Structure of hexafluoroisopropanol unit-containing bioactive compounds **I** and **II**.

In this paper, a hexafluoroisopropanol group was introduced into the structure of the phthalic diamide by using hexafluoroacetone trihydrate as the fluorinating reagent. Ten hexafluoroisopropanol unit-containing flubendiamide analogues were synthesized. Their insecticidal activities against armyworm (*Pseudaletia separata* Walker) were evaluated (Scheme 1, **7a**—**7j**)

Scheme 1 Synthetic pathway of (2-hydroxy)hexafluoroisopropyl-containing flubendiamide analogues **7a**—**7j**



Experimental

All reagents were of analytic grade and obtained from commercial suppliers and used without further purification. Melting points were measured in an open capillary using Büchi melting point B-540 apparatus and are uncorrected. ^{1}H and ^{13}C NMR spectra were recorded on a Bruker AM-400 spectrometer (400 MHz and 100 MHz, respectively) using TMS as the internal standard. DMSO-d_6 was used as NMR solvent for all cases. The ^{19}F NMR spectra were recorded on a Bruker AM-400 spectrometer (376 MHz) using CF_3CO_2H as external standard. Gas chromatography-mass spectra (GC-MS) were recorded on HP 5973 MSD with 6890 GC. High resolution mass spectra (HRMS) were recorded under electron impact conditions using a MicroMass GCT CA 055 instrument.

Synthesis of compounds 1 and 2

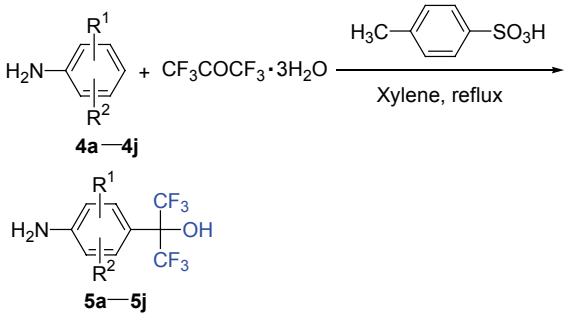
3-Iodophthalic anhydride (**1**) and 1,1-dimethyl-2-methylthioethylamine (**2**) were synthesized according to the methods reported in the literature with some modification.[12]

Synthesis of 3-(1,1-dimethyl-2-methylthioethylimino)-4-iodo-3*H*-isobenzofuran-1-one (3)

The intermediate **3** was synthesized by the reaction of 3-iodophthalic anhydride (**1**) with 1,1-dimethyl-2-methylthioethylamine (**2**) in acetonitrile, followed by cyclization by trifluoroacetic anhydride in acetonitrile.[13] Compound **3** was identified by GC-MS.

Synthesis of 2-(4-aminoaryl)-1,1,1,3,3,3-hexafluoropropan-2-ol (5a—5j)

A solution of hexafluoroacetone trihydrate (2.42 g, 11 mmol) and *p*-toluenesulfonic acid (0.1 g, 0.6 mmol) in 5 mL of xylene was added to substituted anilines **4a**—**4j** (10 mmol) at 90 ℃. The mixture was then stirred at 130 ℃ for about 12 h (monitored by TLC or GC/MS). After the completion of reaction, the solution was cooled to room temperature and the solid precipitate was filtered, washed by petroleum ether.[14] The crude products **5a**—**5j** were obtained (Eq. 1).



(1)

General procedure for the synthesis of the target compounds, hexafluoroisopropanol unit-containing flubendiamide analogues, 7a—7j

To a solution of **3** (3.75 g, 10 mmol) in acetonitrile (50 mL) was added 2-(4-aminoaryl)-1,1,1,3,3,3-hexafluoropropan-2-ol **5a**—**5j** (11 mmol) and trifluoroacetic acid (0.5 mmol). The mixture was then stirred for 3 h. The progress of the reaction was monitored by TLC. When the reaction was complete, without further purification, the intermediate **6a**—**6j** was allowed to react with the solution of *m*-chloroperoxybenzoic acid (22 mmol) in acetonitrile (50 mL). The solution was stirred for another 3 h at room temperature until the reaction was complete. Then the solution was concentrated under reduced pressure and the residue was dissolved in dichloromethane (10 mL). The organic layer was washed by water and dried over anhydrous magnesium sulfate. The CH_2Cl_2 was removed under reduced pressure, and

the residue was purified by silica gel column chromatograph (petroleum ether/ethyl acetate＝1∶1, volume ratio) to afford the target compounds **7a**—**7j**.

***N*²-[1,1-Dimethyl-2-(methylsulfonyl)ethyl]-3-iodo-*N*¹-[4-(1-hydroxy-1-trifluoromethyl-2,2,2-trifluoroethyl)phenyl]-1,2-benzenedicarboxamide (7a)** White solid, m.p.152.0—153.7 ℃, yield 70%; ^{1}H NMR δ: 1.53 (s, 6H, $2CH_3$), 2.94 (s, 3H, CH_3), 3.63 (s, 2H, CH_2), 7.25—7.29 (m, 1H, ArH), 7.65—7.67 (m, 3H, ArH), 7.81—7.83 (m, 2H, ArH), 8.01—8.03 (m, 1H, ArH), 8.31 (s, 1H, NH), 8.62 (s, 1H, OH), 10.37 (s, 1H, NH); ^{19}F NMR δ: −74.09——74.07 (m, 6F, $2CF_3$); ^{13}C NMR δ: 27.1, 43.7, 52.9, 53.4, 58.7, 61.2, 95.8, 119.8, 125.9, 127.7, 127.9, 130.6, 136.7, 141.0, 141.2, 141.8, 166.1, 168.0. HRMS (EI) calcd for $C_{22}H_{21}F_6IN_2O_5SNa$ $[M+Na]^+$ 689.0018, found 689.0022.

***N*²-[1,1-Dimethyl-2-(methylsulfonyl)ethyl]-3-iodo-*N*¹-[4-(1-hydroxy-1-trifluoromethyl-2,2,2-trifluoroethyl)-2-methylphenyl]-1,2-benzenedicarboxamide (7b)** White solid, m.p. 232.2—234.9 ℃, yield 80%; ^{1}H NMR δ: 1.53 (s, 6H, $2CH_3$), 2.32 (s, 3H, CH_3), 2.94 (s, 3H, CH_3), 3.64 (s, 2H, CH_2), 7.25—7.29 (m, 1H, ArH), 7.50—7.55 (m, 2H, ArH), 7.67—7.72 (m, 2H, ArH), 8.00—8.02 (m, 1H, ArH), 8.38 (s, 1H, NH), 8.66 (s, 1H, OH), 9.69 (s, 1H, NH); ^{19}F NMR δ: −73.89 (s, 6F, $2CF_3$); ^{13}C NMR δ: 14.5, 18.6, 21.2, 26.6, 43.6, 52.9, 60.2, 61.3, 95.9, 125.1, 127.8, 127.9, 129.3, 130.6, 132.6, 136.6, 138.3, 141.2, 141.8, 166.0, 168.2. HRMS (EI) calcd for $C_{23}H_{23}F_6IN_2O_5SNa$ $[M+Na]^+$ 703.0174, found 703.0173.

***N*²-[1,1-Dimethyl-2-(methylsulfonyl)ethyl]-3-iodo-*N*¹-[4-(1-hydroxy-1-trifluoromethyl-2,2,2-trifluoroethyl)-2,3-dimethylphenyl]-1,2-benzenedicarboxamide (7c)** White solid, m.p. 197.1—201.9 ℃, yield 78%; ^{1}H NMR δ: 1.58 (s, 6H, $2CH_3$), 2.13 (s, 3H, CH_3), 2.30 (s, 3H, CH_3), 2.50 (s, 3H, CH_3), 3.36 (s, 2H, CH_2), 7.23—7.34 (m, 3H, ArH), 7.84—7.85 (m, 1H, ArH), 8.01—8.03 (m, 1H, ArH), 8.56 (s, 1H, NH), 9.09 (s, 1H, OH), 9.58 (s, 1H, NH); ^{19}F NMR δ: −73.74 (s, 3F, CF_3), −70.84 (s, 3F, CF_3); ^{13}C NMR δ: 14.5, 16.2, 20.7, 26.5, 27.2, 43.7, 53.0, 60.2, 61.4, 96.6, 125.3, 128.0, 128.2, 130.6, 135.7, 136.2, 137.8, 140.4, 141.6, 142.5, 164.2, 168.7. HRMS (EI) calcd for $C_{24}H_{25}F_6IN_2O_5SNa$ $[M+Na]^+$ 717.0331, found 717.0336.

***N*²-[1,1-Dimethyl-2-(methylsulfonyl)ethyl]-3-iodo-*N*¹-[4-(1-hydroxy-1-trifluoromethyl-2,2,2-trifluoroethyl)-2,6-dimethylphenyl]-1,2-benzenedicarboxamide (7d)** White solid, m.p. 200.1—202.5 ℃, yield 77%; ^{1}H NMR δ: 1.57 (s, 6H, $2CH_3$), 2.30 (s, 6H, $2CH_3$), 3.02 (s, 3H, CH_3), 3.69 (s, 2H, CH_2), 7.27—7.31 (m, 1H, ArH), 7.41 (s, 2H, ArH), 7.76—7.78 (m, 1H, ArH), 8.01—8.03 (m, 1H, ArH), 8.41 (s, 1H, NH), 8.67 (s, 1H, OH), 9.81 (s, 1H, NH); ^{19}F NMR δ: −73.74 (s, 6F, $2CF_3$); ^{13}C NMR δ: 18.9, 26.7, 27.2, 43.6, 52.8, 61.6, 96.4, 126.5, 127.7, 127.7, 129.4, 130.5, 136.5, 136.6, 137.1, 141.3, 142.5, 165.5, 168.2. HRMS (EI) calcd for $C_{24}H_{25}F_6IN_2O_5SNa$ $[M+Na]^+$ 717.0331, found 717.0320.

***N*²-[1,1-Dimethyl-2-(methylsulfonyl)ethyl]-3-iodo-*N*¹-[4-(1-hydroxy-1-trifluoromethyl-2,2,2-trifluoroethyl)-2-fluorophenyl]-1,2-benzenedicarboxamide (7e)** White solid, m.p. 78.1—84.3 ℃, yield 70%; ^{1}H NMR δ: 1.52 (s, 6H, $2CH_3$), 2.95 (s, 3H, CH_3), 3.36 (s, 2H, CH_2), 7.25—7.29 (m, 1H, ArH), 7.53—7.55 (m, 2H, ArH), 7.68—7.70 (m, 1H, ArH), 8.02—8.09 (m, 2H, ArH), 8.38 (s, 1H, NH), 8.94 (s, 1H, OH), 10.12 (s, 1H, NH); ^{19}F NMR δ: −121.60——121.55 (m, 1F, ArF), −74.07 (s, 6F, $2CF_3$); ^{13}C NMR δ: 14.5, 26.5, 43.6, 52.9, 60.2, 95.8, 123.5, 124.6, 124.7, 128.0, 128.1, 128.2, 128.5, 128.6, 130.6, 135.8, 141.5, 141.7, 166.1, 168.1. HRMS (EI) calcd for $C_{22}H_{20}F_7IN_2O_5Na$ $[M+Na]^+$ 706.9924, found 706.9925.

***N*²-[1,1-Dimethyl-2-(methylsulfonyl)ethyl]-3-iodo-*N*¹-[4-(1-hydroxy-1-trifluoromethyl-2,2,2-trifluoroethyl)-2-chlorophenyl]-1,2-benzenedicarboxamide (7f)** White solid, m.p. 84.8—91.4 ℃, yield 70%; ^{1}H NMR δ: 1.52 (s, 6H, $2CH_3$), 2.96 (s, 3H, CH_3), 3.65 (s, 2H, CH_2), 7.25—7.30 (m, 2H, ArH), 7.37—7.41 (m, 1H, ArH), 7.53—7.55 (m, 1H, ArH), 7.80—7.82 (m, 1H, ArH), 8.02—8.04 (m, 1H, ArH), 8.42 (s, 1H, NH), 9.13 (s, 1H, OH), 9.70 (s, 1H, NH); ^{19}F NMR δ: −74.09 (s, 6F, $2CF_3$); ^{13}C NMR δ: 27.1, 43.7, 53.5, 58.8, 61.2, 96.0, 126.4, 127.3, 127.4, 127.9, 128.1, 130.1, 130.7, 135.2, 136.0, 141.5, 141.8, 156.2, 156.5, 168.2. HRMS (EI) calcd for $C_{22}H_{21}ClF_6IN_2O_5S$ $[M+H]^+$ 700.9809, found 700.9805.

***N*²-[1,1-Dimethyl-2-(methylsulfonyl)ethyl]-3-iodo-*N*¹-[4-(1-hydroxy-1-trifluoromethyl-2,2,2-trifluoroethyl)-2-ethylphenyl]-1,2-benzenedicarboxamide (7g)** White solid, m.p. 103.7—106.4 ℃, yield 71%; ^{1}H NMR δ: 1.18 (t, J＝7.4 Hz, 3H, CH_3), 1.55 (s, 6H, $2CH_3$), 2.96 (q, J＝7.4 Hz, 2H, CH_2), 2.96 (s, 3H, CH_3), 3.66 (s, 2H, CH_2), 7.26—7.30 (m, 1H, ArH), 7.52—7.54 (m, 1H, ArH), 7.59—7.64 (m, 2H, ArH), 7.69—7.71 (m, 1H, ArH), 8.01—8.03 (m, 1H, ArH), 8.36 (s, 1H, NH), 8.71 (s, 1H, OH), 9.74 (s, 1H, NH); ^{19}F NMR δ: −74.12 (s, 6F, $2CF_3$); ^{13}C NMR δ: 27.1, 28.0, 43.7, 53.5, 57.8, 58.9, 59.3, 89.9, 111.6, 114.5, 117.3, 120.2, 123.0, 131.8, 135.7, 145.7, 155.8, 156.2, 156.5, 156.9, 167.5, 167.9. HRMS (EI) calcd for $C_{24}H_{25}F_6IN_2O_5SNa$ $[M+Na]^+$ 717.0331, found 717.0337.

***N*²-[1,1-Dimethyl-2-(methylsulfonyl)ethyl]-3-iodo-*N*¹-[4-(1-hydroxy-1-trifluoromethyl-2,2,2-trifluoroethyl)-2-isopropylphenyl]-1,2-benzenedicarboxamide (7h)** White solid, m.p. 104.5—107.1 ℃, yield 76%; ^{1}H NMR δ 1.18 (d, J＝6.8 Hz, 6H, $2CH_3$), 1.56 (s, 6H, $2CH_3$), 1.84 (s, 1H, CH), 2.96 (s, 3H, CH_3), 3.66 (s, 2H, CH_2), 7.26—7.30 (m, 1H, ArH), 7.52 (s, 2H, ArH), 7.65 (s, 1H, ArH), 7.70—7.72 (m, 1H, ArH), 8.01—8.03 (m, 1H, ArH), 8.36 (s, 1H, NH), 8.70 (s, 1H, OH), 9.77 (s, 1H, NH); ^{19}F NMR δ: −73.87 (s, 6F, $2CF_3$); ^{13}C NMR δ: 23.7, 26.7, 27.7, 43.7, 52.9, 61.5, 96.1, 124.8, 124.9, 127.3, 127.7, 129.1, 130.6, 136.5, 136.9, 141.2, 142.1, 144.1, 165.2, 166.5, 168.1, 170.9. HRMS (EI) calcd for $C_{25}H_{27}F_6IN_2O_5SNa$ $[M+Na]^+$ 731.0487, found 731.0488.

***N*^{2}-[1,1-Dimethyl-2-(methylsulfonyl)ethyl]-3-iodo-*N*^{1}-[4-(1-hydroxy-1-trifluoromethyl-2,2,2-trifluoroethyl)-2-bromophenyl]-1,2-benzenedicarboxamide** (**7i**) White solid, m.p. 105.8—108.2 ℃, yield 75%; ^{1}H NMR δ: 1.55 (s, 6H, 2CH_3), 2.96 (s, 3H, CH_3), 3.68 (s, 2H, CH_2), 7.29—7.33 (m, 1H, ArH), 7.74—7.76 (m, 2H, ArH), 7.95—7.98 (m, 2H, ArH), 8.05—8.07 (m, 1H, ArH), 8.47 (s, 1H, NH), 9.03 (s, 1H, OH), 9.80 (s, 1H, NH); ^{19}F NMR δ: −74.02 (s, 6F, CF_3); ^{13}C NMR δ: 26.2, 43.2, 52.5, 59.8, 60.7, 95.6, 117.4, 126.0, 126.8, 127.4, 129.2, 130.3, 131.1, 135.3, 138.0, 141.2, 141.4, 165.4, 167.6, 170.3. HRMS (EI) calcd for $C_{22}H_{21}BrF_6IN_2O_5S$ $[M+H]^+$ 744.9304, found 744.9453.

***N*^{2}-[1,1-Dimethyl-2-(methylsulfonyl)ethyl]-3-iodo-*N*^{1}-[4-(1-hydroxy-1-trifluoromethyl-2,2,2-trifluoroethyl)-2,3-difluorophenyl]-1,2-benzenedicarboxamide** (**7j**) White solid, m.p. 133.1—135.4 ℃, yield 69%; ^{1}H NMR δ: 1.52 (s, 6H, 2CH_3), 2.98 (s, 3H, CH_3), 3.71 (s, 2H, CH_2), 7.26—7.32 (m, 3H, ArH), 7.64—7.66 (m, 1H, ArH), 8.07—8.09 (m, 1H, ArH), 8.82 (s, 1H, NH), 9.25 (s, 1H, OH), 10.36 (s, 1H, NH); ^{19}F NMR δ: −134.37 (d, J=19.9 Hz, 1F, ArF), −131.98 (d, J=22.2 Hz, 1F, ArF), −73.32 (s, 6F, 2CF_3); ^{13}C NMR δ: 27.1, 43.4, 53.2, 58.9, 94.9, 126.2, 127.2, 127.8, 127.9, 128.4, 128.5, 128.6, 128.7, 129.3, 130.9, 131.1, 136.5, 141.8, 166.0, 168.9. HRMS (EI) calcd for $C_{22}H_{19}F_8IN_2O_5SNa$ $[M+Na]^+$ 724.9829, found 724.9836.

Results and Discussion

In our previous paper, we successfully introduced a heptafluoroisopropyl group into the structure of the benzoylphenylurea by using 2-iodoheptafluopropane as the fluorinating reagent.[15] Some of heptafluoroisopropyl-containing benzoylphenylurea exhibited excellent insecticidal activity. However, heptafluoroisopropyl iodide is not a good starting material with regard to handling and price.

Hexafluoroacetone trihydrate, a cheap, stable and commercially available fluorinated building block, is widely used in organic synthesis and materials industry.[16] The 1,1,1,3,3,3-hexafluoro-2-hydroxy-propan-2-yl group could be conveniently introduced by a Friedel-Crafts type of reaction between an aniline and hexafluoroacetone hydrate in the presence of an acid, as shown in Scheme 2. When electron-donating group such as methyl, ethyl and methoxy was substituted at the *ortho* position to the amino group, the reaction proceeded smoothly. The substituted aniline having chlorine, boromine and fluorine atom on the aromatic moiety is unfavourable for the reaction and afforded 2-amino aryl hexafluoroisoropanols in relatively low yields. The position of the substituent on the aniline derivatives played an important role in this reaction. When the *meta* position of the amino group was substituted by other substituent, no matter whether it is an electron-withdrawing group or an electron-donating group, the Friedel-Crafts reaction can not proceed efficiently. This is due to the steric effect of the substituent attached at the *meta* position relative to the amino group.

The synthesis of **7b** from the intermediate **3** was served as the model reaction to investigate the effect of solvent on the yields of **7a**—**7j**. According to literature,[9b] toluene, dichloromethane, acetonitrile, and ethyl acetate were frequently used as reaction solvents to prepare **7a**—**7j**, but after many trials, it was found that acetonitrile is a more suitable solvent for both the amination of **3** and oxidation of **6a**—**7j** because of its low toxicity and simple workup.

The yield was also significantly affected by the amount of *m*-chloroperoxybenzoic acid. The results of experiments indicated that when the molar ratio of **3** to *m*-chloroperoxybenzoic acid was 1∶2.2, the oxidation of **6a**—**6j** could be carried out successfully and gave the expected compounds in moderate yields. A further increase in the amount of *m*-chloroperoxybenzoic acid showed no substantial improvement in the yield, whereas the yield was reduced if the ratio is less than 2.

Under these optimized reaction conditions, a series of hexafluoroisopropanol unit-containing flubendiamide analogues **7a**—7**j** were synthesized by the reaction of hexafluoroisopropanol unit-containing anilies **5a**—**5j** with **3**, followed by cyclization by trifluoroacetic anhydride in acetonitrile.

Table 1 Insecticidal activity against oriental armyworm of compounds **7a**—**7j**

Compd.	R^1, R^2	Concentration/ ($mg \cdot L^{-1}$)	Insecticidal activity/%
7a	H, H	500	50
		5	100
7b	2-methyl, H	2.5	100
		0.6	80
7c	2,3-dimethyl	100	10
7d	2,6-dimethyl	100	50
7e	2-fluoro, H	10	50
7f	2-chloro, H	10	50
7g	2-ethyl, H	500	50
7h	2-isopropyl, H	500	100
7i	2-bromo, H	500	30
7j	2,3-difluoro	500	48
flubendiamide[a]		0.6	100

[a] The flubendiamide was synthesized by our laboratory according to the literature. The purity is determined by m.p. and ^{1}H NMR (>95%).

The insecticidal activities of the title compounds **7a**—**7j** against armyworm were evaluated according to the literature procedures.[17] To compare their activities, the commercial product flubendiamide was tested under the same conditions. The insecticidal activity of **7a**—**7j** against armyworm is summarized in Table 1. It was found that the position and kind of substituent group

attached to the aniline ring has a profound influence on the activity of the hexafluoroisopropanol unit-containing flubendiamide analogues **7a**—**7j**. Among the ten compounds tested, some of them exhibited good insecticidal activities (**7e** and **7f**). Compound **7b** is the most active compound, its insecticidal activity against armyworm at 0.6 mg/L is 80%, which is slightly weaker than the corresponding flubendiamide. The only difference in structure between **7b** and flubendiamide is that heptafluoroisopropyl group in the anilide moiety is replaced with 2-hydroxy hexafluoroisopropyl group.

In addition, the insecticidal activities of compound **7b** against other insects were also evaluated (Table 2). Bioassays were conducted according to the method described by Wang.[18] The results indicated that compound **7b** exhibited high activities against all test insects.

Table 2 The insecticidal activities of compound **7b** against other insects

Insect	Concentration/ ($mg \cdot L^{-1}$)	Insecticidal activity/%
Mosquito (*Culex pipiens pallens*)	1	100
	0.5	80
Cotton bollworm (*Helicoverpa armigera*)	100	100
	50	30
Asiatic Corn Borer (*Ostrinia furnacalis*)	25	100
	10	60
Diamondback moth (*Plutella xyllostella*)	12.5	100
Beet armyworm (*Spodoptera exigua*)	50	90
	25	80
Tobacco cutworm (*Spodoptera litura*)	25	80
	12.5	50

In summary, on the basis of commercial insecticides flubendiamide, a series of novel analogues of flubendiamide containing a hexafluoroisopropanol moiety were synthesized via the key intermediate, 4-[(2-hydroxy)-hexafluoroisopropyl] aniline. Their insecticidal activities against armyworm were evaluated. Compound **7b** exhibited nearly the same insecticidal activity as the corresponding commercial product flubendiamide against armyworm and had broad spectrum of activity against several other insects.

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(Cheng, F.)

