

Fluorosulfonated Thiophenols and Their Effects on Plants

Ivan C. Popoff,* J. Ray Frank,¹ Chandrakant B. Thanawalla, and Richard A. Creager¹

Eight variously substituted fluorosulfonated thiophenols and 14 precursors were synthesized and evaluated as plant response agents. They were less

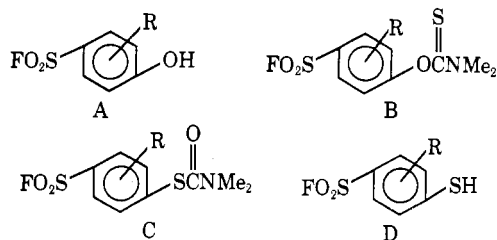
active than the corresponding fluorosulfonated phenols.

Some fluorosulfonated phenols are not only very active desiccants but have also proved to be exceptional in their speed of desiccation (Popoff *et al.*, 1969). There is strong evidence that the free phenolic hydroxyl is at least partly responsible for the activity of these products. Furthermore, it appeared that the degree and speed of desiccation was enhanced as the acidity of the phenol was increased. It was therefore of interest to compare some fluorosulfonated thiophenols with the corresponding phenols in regard to their effects on plants, because the acidity of the SH group is higher than that of the OH group.

A six species test was chosen for this study because it appeared to be a reliable indicator for the activity observed in the field tests in our previous work with fluorosulfonated phenols (Popoff *et al.*, 1969). A direct comparison with the activity of the corresponding phenols was possible since the effects measured for the thiophenols were qualitatively the same as those observed for the phenols in the same six species test (Popoff *et al.*, 1969).

PRODUCTS

With the exception of the oily 2-fluoro-4-fluorosulfonylthiophenol (IID), the products tested were thoroughly purified prior to screening; IID contained small amounts of di[(2-fluoro-4-fluorosulfonyl)phenyl] disulfide. The analytical data, yields, and melting points of the compounds having the structures B, C, and D are listed in Table I. The fluorosulfonated phenols A (Table II) have been described previously (Popoff *et al.*, 1969).



The fluorosulfonated thiophenols (D) were obtained from the corresponding fluorosulfonated phenols (A) *via* the two intermediates (B) and (C). Thus, heating the *S*-phenyl thiocarbamates (C) in strong sulfuric acid affected only the amide moiety but not the fluorosulfonyl group, and yielded the desired thiophenols (D). This hydrolysis is described in detail

for the preparations of IID and IVD in the syntheses section. With minor variations, the IVD method was used to prepare the remaining six final products. With two exceptions, *i.e.* IIIC and VC, the *S*-phenyl thiocarbamates (C) were obtained by the thermal rearrangement (Edwards and Pianka, 1965) of the *O*-phenyl thiocarbamates (B). The compounds IIIC and VC resulted directly from the reactions of *N,N*-dimethylthiocarbamyl chloride with the corresponding fluorosulfonated phenols IIIA and VA, since the *O*-phenyl thiocarbamates IIIB and VB expected from these reactions were not stable and isomerized to IIIC and VC even at room temperature. Apparently the presence of the highly electron-withdrawing nitro group in addition to the fluorosulfonyl in structures B (IIIB and VB) is responsible for the very facile isomerization of B to C. The replacement of the ortho positioned NO₂ group of VC with a meta positioned or ortho positioned chlorine does not facilitate the rearrangement sufficiently since the dichlorinated IVB, VIIB, and VIIIB were obtained analytically pure in 43–78% yield. Thus the six stable *O*-phenyl thiocarbamates (B) were obtained by reacting the fluorosulfonated phenols (A) dimethylthiocarbamyl chloride in the presence of an HCl acceptor.

TESTING PROCEDURE

Seven-day-old plants of the following species were used: black Valentine bean (*Phaseolus vulgaris*), heavenly blue morning glory (*Convolvulus purpureus*), scarlet globe radish (*Raphanus sativus*), Lincoln soybean (*Glycine max*), Clinton oats (*Avena sativa*), and PI-9790 rice (*Oryza sativa*). These plants can be grown easily and uniformly in 1 qt plastic containers. The screening data obtained with them are easily reproducible. The broadleaf species were thinned to two plants per pot prior to treatment. The two grasses—*i.e.*, oats and rice—were not thinned. Two pots of each species were used for each spraying. The candidate compounds were sprayed at the rates of 1.0 and 0.1 lb per acre. Samples used were 31 and 3 mg, respectively, dissolved in 12 ml of acetone containing 0.5% Tween-20, and sprayed on an area of 0.33 sq yd.

Observations were made after 1, 5, and 10 to 14 days and the optimum activity was used for the final rating. All plants were observed for extent of abscission, desiccation, kill, and various growth regulator effects. The following ratings were used: no effect (0%)—rating 1; slight effect (1 to 25%)—rating 2; moderate effect (26 to 75%)—rating 3; severe effect (76 to 100%)—rating 4. There could not be a rating higher than 4 for any one of the species even if the compound had "severe effect" in several of the responses. A chemical causing extreme effect on each of the six species received the rating 24. A chemical causing no effect on two species (2 ×

Pennwalt Corp., King of Prussia, Pennsylvania 19406.

¹ Present address: Plant Physiology Division, Plant Sciences Laboratories, Department of the Army, Fort Detrick, Frederick, Maryland 21701.

Table I. Fluorosulfonated Thiophenols and Their Precursors

No. ^a	R ^b	Mp, °C	Yield %	Calcd %			Found %		
				C	H	N	C	H	N
IB	2-Cl	155-56	65	36.27	3.02	4.71	36.48	2.95	4.89
C		93-94.5	79			4.71			4.81
D		53-55	70	31.79	1.77	8.38 ^c	31.89	1.84	8.48 ^c
IIB	2-F	137-38.5	58	38.42	3.22	4.97	38.68	3.48	5.02
C		94-96	98	38.42	3.22		38.88	3.59	
D		Oil ^d	48	34.28	1.91	30.50 ^e	34.29	2.27	29.82 ^e
IIIC	2-NO ₂	90.5-92	98	35.04	2.94	9.08	35.00	3.23	9.02
D		84-87	72	30.37	1.69	27.03 ^e	30.78	1.82	26.95 ^e
IVB	2,6-Cl ₂	143-45	43	32.54	2.43	4.21	32.92	2.81	4.54
C		127-28	99	32.54	2.43	4.21	32.43	2.38	4.32
D		71-72	96	27.59	1.15	7.27 ^c	27.66	1.23	7.22 ^c
VC	2-Cl-6-NO ₂	125-26	80	31.53	2.35	8.17	31.51	2.56	8.58
D		70.5-72	95	26.52	1.11	6.99 ^c	26.90	1.36	7.18 ^c
VIB	2-Cl-6-Me	158-60	90	38.52	3.55	4.49	38.90	3.59	4.46
C		119-21	91	38.52	3.55	4.49	38.80	3.60	4.58
D		68-70	94	34.93	2.51	26.64 ^e	35.23	2.66 ^f	26.65 ^e
VIIIB	2,3-Cl ₂	165-66	78	32.54	2.42		32.86	2.53	
C		107-109	93	32.54	2.42	4.21	32.66	2.53	4.61
D		55-56	93	27.59	1.15	24.55 ^e	27.60	1.32 ^g	24.84 ^e
VIIIB	2,5-Cl ₂	103-104	56	32.54	2.42	4.21	32.42	2.42	4.41
C		135-36	85	32.54	2.42	4.21	32.24	2.54	4.26
D		92-93	94	27.59	1.15	7.27 ^c	27.74	1.29	7.12 ^c

^a The letters B, C, and D refer to structures B (thiocarbamate of the phenol A), C (carbamate of the thiophenol D), and D (thiophenol). ^b The position of R is relative to the amide moiety or SH of B, C, and D. ^c % F instead of % N. ^d Crude; on standing the oil deposits a solid which is the corresponding disulfide [FSO₂C₆H₃(F)₂S₂, mp 118-119 °C [Calcd: C, 34.44; H, 1.44; F, 18.16; Found: C, 34.76; H, 1.63; F, 18.09; absence of -SH (ir and -SH determination)]. ^e % S instead of % N. ^f Also mercaptan-S. Calcd: 13.49; Found: 13.32. ^g Also mercaptan-S. Calcd: 12.27; found: 11.89.

Table II. Test Results

Product no.	Rating at lb/acre and total rating (Σ) ^b (structure no. ^a)												Loss of activity A → D Σ _A -Σ _D
	A ^c			B			C			D			
	0.1	1.0	Σ ^b	0.1	1.0	Σ ^b	0.1	1.0	Σ ^b	0.1	1.0	Σ ^b	
I	18	22	40	10	11	21	6	6	12	6	14	20	20
II	15	23	38	6	6	12	6	9	15	6	12	18	20
III	6	10	16	<i>d</i>	<i>d</i>	<i>d</i>	6	9	15	6	9	15	1
IV	16	24	40	8	11	19	6	6	12	9	19	28	12
V	6	8	14	<i>d</i>	<i>d</i>	<i>d</i>	6	8	14	6	6	12	2
VI	13	16	29	8	11	19	6	6	12	7	13	20	9
VII	8	20	28	6	6	12	6	6	12	6	11	17	11
VIII	18	24	42	7	10	17	6	6	12	6	13	19	23

^a See Note a of Table I. ^b Represents the sum of the ratings for 0.1 and 1.0 lb/acre. ^c Popoff *et al.* (1969). ^d Compound not synthesized.

1 = 2), slight effect on three (3 × 2 = 6), and severe effect on one (1 × 4 = 4) was rated 2 + 6 + 4 = 12. The sum of the ratings for 0.1 and 1.0 lb per acre of each compound represents the total rating (Σ); it is convenient for a quick comparison of the plant response activity. A chemical causing no effect on all six species at both rates per acre would have a total rating (Σ) of 12; its (Σ) would be 48 if its effect was severe (76 to 100%) for the six species. Table II lists the results of this six species test.

DISCUSSION OF RESULTS

Eight ring-substituted *p*-fluorosulfonated thiophenols (D) representing a new class of thiophenols, and their *S*-(*N,N*-dimethylcarbamates) (C) were synthesized. Their plant response activity was compared with that of the corresponding ring-substituted *p*-fluorosulfonated phenols (A) and their *O*-(*N,N*-dimethylthiocarbamates) (B). Structures B are isomeric with structures C.

The sulfur analogs ID, IID, IVD, and VIIID of the highly active phenols IA, IIA, IVA, and VIIIA caused a considerably lower plant response than their oxygen analogs. The loss of activity of D relative to A was much greater for ID, IID, and

VIIID than for IVD and VID. It should be noted that IVD and VID contain an SH group which is to some extent sterically hindered by two ortho positioned substituents and would be more difficult to oxidize to disulfide than the thiol moiety of ID, IID, or VIIID. Indeed the thiophenol IID is slowly oxidized to the corresponding disulfide (which was slightly less active than IID) merely by exposure to air [see Note d of Table I]. Thus we can assume that the expected enhanced effect due to the higher acidity of the thiophenols (over the acidity of the phenols) was overshadowed by the deactivation of the free SH group *via* disulfide formation. This assumption is supported by the generally lower activity resulting from the conversion of the SH containing structures (D) to the *S*-carbamate structures (C).

The activity relationship between the *O*-phenyl thiocarbamates (B) and the free phenols (A) is in agreement with the previously expressed assumption that the phenolic hydroxyl participates in the mode of action of this class of compounds. If an hydrolysis precedes the plant response of structures B and C, the lower activity observed for the carbamates C is not surprising on the basis of the lower activity of the thiophenols D.

The speculation that the hydrogen bonding and/or the effect of the strong electronegativity of the nitro group on the hydrolytic stability of the fluorosulfonyl are responsible for the low activity of IIIA and VA is supported by the low activity of the *o*-nitrothiophenols IIID and VD.

SYNTHESES

The ir spectra [6.35–6.45 μ for $-C(S)NMe_2$ (B); 5.90–6.00 μ for $-C(O)NMe_2$ (C); 3.85–3.90 μ for $-SH$ (D)] and elemental analyses (Table I) confirmed the structures of the products. All temperatures are given in $^{\circ}C$. 2,6-Dichloro-*O*-(*N,N*-dimethylthiocarbamyl)-4-fluorosulfonylphenol (IVB) was obtained from 2,6-dichloro-4-fluorosulfonylphenol (IVA) by the method described for IB. The IIB method was used for the synthesis of VIB and VIIIB, which were recrystallized from a *tert*-butanol–2-propanol mixture (4 to 1) and methyl ethyl ketone–methanol–water (5 to 8 to 8), respectively. The thiophenols ID, IIID, VD, VID, and VIID were prepared by the hydrolysis of their corresponding (C) compounds as described for IVD, including the following variations. ID, the crude product was recrystallized from petroleum ether (bp 30–60 $^{\circ}C$); IIID and VD, the solid was extracted with hexane and petroleum ether (bp 30–60 $^{\circ}C$), respectively, in a Soxhlet; the residue of the evaporated extract was the product; hexane was the recrystallization solvent for VID and VIID. The IVD method was used without any changes for the synthesis of VIIID. The hydrolyses of structures C can be also carried out by a 2 to 3-hr stirring at 80 $^{\circ}C$ in 87% sulfuric acid instead of 14 to 18 hr at 55–60 $^{\circ}C$.

2-Chloro-*O*-(*N,N*-dimethylthiocarbamyl)-4-fluorosulfonylphenol (IB). A solution of 31.6 g of 2-chloro-4-fluorosulfonylphenol (IA), 18.5 g of *N,N*-dimethylthiocarbamyl chloride, and 22.7 g of triethylamine in 200 ml of benzene was refluxed for 2 hr. The reaction mixture was filtered, the solid was thoroughly washed with ether, and the combined ether–benzene filtrate was evaporated. The residue was recrystallized (Darco) from hexane–benzene (1 to 1) to obtain 29.0 g (65%) of the desired product (mp 155–156 $^{\circ}C$).

2-Fluoro-*O*-(*N,N*-dimethylthiocarbamyl)-4-fluorosulfonylphenol (IIB). A solution of 32.6 g of 2-fluoro-4-fluorosulfonylphenol (IIA), 23.0 g of *N,N*-dimethylthiocarbamyl chloride, and 18.7 g of *N*-methylmorpholine in 150 ml of methyl ethyl ketone was refluxed for 18 hr and filtered hot. The filter cake was washed with 50 ml of hot methyl ethyl ketone and the combined filtrate was evaporated. The residue was thoroughly washed with water and recrystallized from 2-propanol to obtain 27.5 g (58%) of the white product (mp 137–138.5 $^{\circ}C$).

2,3-Dichloro-*O*-(*N,N*-dimethylthiocarbamyl)-4-fluorosulfonylphenol (VIIIB). A solution of 39.0 g of VIIA, 22.4 g of *N,N*-dimethylthiocarbamyl chloride, and 18.2 g of *N*-methylmorpholine in 150 ml of dioxane was stirred for 18 hr at room temperature and filtered. The filter cake was washed with 15 ml of dioxane followed by water to obtain 41.3 g (78%) of the desired product (mp 165–166 $^{\circ}C$).

2-Chloro-*S*-(*N,N*-dimethylthiocarbamyl)-4-fluorosulfonylthiophenol (IC). A suspension of 11.5 g of the phenylthiocarbamate IB in 40 ml of tetramethylene sulfone was stirred for 40 min at 195–200 $^{\circ}C$ and poured in 50 ml of ice water. The precipitate was recrystallized from hexane to obtain 9.1 g (79%) of the product (mp 93–94.5 $^{\circ}C$).

***S*-(*N,N*-Dimethylthiocarbamyl)-2-fluoro-4-fluorosulfonylthiophenol (IIC).** The melt of 13.7 g of IIB was stirred for 7 min at 190 $^{\circ}C$. On cooling there was obtained 13.3 g (98%) of the desired product (mp 94–96 $^{\circ}C$).

***S*-(*N,N*-Dimethylthiocarbamyl)-4-fluorosulfonyl-2-nitrothiophenol (IIIC).** A solution of 22.1 g of 4-fluorosulfonyl-2-nitrothiophenol (IIIA), 13.6 g of *N,N*-dimethylthiocarbamyl chloride, and 11.0 g of *N*-methylmorpholine in 60 ml of acetone was prepared at 5 to 10 $^{\circ}C$ and stirred for 18 hr at room temperature. The reaction mixture was filtered and the solid (*N*-methylmorpholine hydrochloride) was washed with 100 ml of acetone. The combined acetone filtrate was evaporated *in vacuo* at room temperature and the residue was triturated with water to obtain 30.3 g (98%) of the yellow product (mp 90–92 $^{\circ}C$, not changed after recrystallization from methanol).

2,6-Dichloro-*S*-(*N,N*-dimethylthiocarbamyl)-4-fluorosulfonylthiophenol (IVC). The melt of 11.5 g of the phenylthiocarbamate IVB was stirred for 20 min at 160 $^{\circ}C$. On cooling there was obtained 11.4 g (99%) of the desired product (mp 127–128 $^{\circ}C$).

2-Chloro-*S*-(*N,N*-dimethylthiocarbamyl)-4-fluorosulfonyl-6-nitrothiophenol (VC), mp 125–126 $^{\circ}C$, was obtained in 80% yield as described for IIC using 2-chloro-4-fluorosulfonyl-6-nitrophenol (VA) instead of IIIA in dioxane.

2-Chloro-*S*-(*N,N*-dimethylthiocarbamyl)-4-fluorosulfonyl-6-methylthiophenol (VIC). The melt of 15.6 g of VIB was stirred for 22 min at 180–185 $^{\circ}C$. Since the crude product was brownish, it was dissolved in chloroform and decolorized with Darco. The evaporation residue of the chloroform solution was triturated with 40 ml of a *tert*-butanol–2-propanol mixture (4 to 1) to obtain 14.2 g (91%) of the pure product (mp 119–121 $^{\circ}C$).

2,3-Dichloro-*S*-(*N,N*-dimethylthiocarbamyl)-4-fluorosulfonylthiophenol (VIIC). The melt of 16.6 g of VIIIB was stirred for 25 min at 160–165 $^{\circ}C$. The crude product was recrystallized from a *tert*-butanol–2-propanol mixture (4 to 1) to obtain 14.4 g (93%) of the pure product (mp 107–09 $^{\circ}C$).

2,5-Dichloro-*S*-(*N,N*-dimethylthiocarbamyl)-4-fluorosulfonylthiophenol (VIIC). mp 135–136 $^{\circ}C$, was obtained in 85% yield as described for VIIC using VIIIB instead of VIB and recrystallizing from petroleum ether (bp 30–60 $^{\circ}C$)–chloroform (1 to 1).

2-Fluoro-4-fluorosulfonylthiophenol (IID). A suspension of 14.7 g of the carbamate IIC in 30 ml of 87% sulfuric acid was stirred for 14 hr at 55–60 $^{\circ}C$, poured onto 150 g of ice, and extracted with 200 ml of chloroform. The water washed and dried (Na_2SO_4) extract was evaporated and the residue was extracted with hot hexane (6 \times 100 ml). Evaporation of the hexane gave 5.5 g (48%) of the oily product ($-SH$). By the time it was tested the oil contained small amounts of a solid which was di-(2-fluoro-4-fluorosulfonylphenyl) disulfide [see Note e of Table I].

2,6-Dichloro-4-fluorosulfonylthiophenol (IVD). A suspension of 12.5 g of the carbamate IVC in 25 ml of 87% sulfuric acid was stirred for 18 hr at 55 to 60 $^{\circ}C$, cooled, and filtered. The solid was washed thoroughly with water and dried to obtain 9.4 g (96%) of the yellowish product (mp 71–72 $^{\circ}C$).

ACKNOWLEDGMENT

The elemental analyses were carried out by Pennwalt's Analytical Department.

LITERATURE CITED

- Edwards, J. D., Pianka, M., *J. Chem. Soc.* 7338 (1965).
Popoff, I. C., Frank, J. R., Whitaker, R. L., Miller, J. H., Demaree, K. D., *J. AGR. FOOD CHEM.* 17, 810 (1969).

Received for review June 21, 1971. Accepted August 11, 1971.