Synthesis and Herbicidal Activity of 5-(Haloalkyl)-Substituted Thiazolo[4,5-*b*]pyridine-3(2*H*)-acetic Acid Derivatives

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Several examples of 5-(haloalkyl)-substituted thiazolo[4,5-*b*]pyridine-3(2*H*)-acetic acid derivatives were synthesized as pyridine analogues of the commercial herbicide benazolin. Most of the compounds in this study exhibited auxin-like herbicidal symptoms and higher activity on dicotyledonous than on monocotyledonous species. Among the derivatives, acids and esters were significantly more active than alkoxyamides. In addition, a combination of 2-oxo and 6-chloro substituents provided higher activity than others on certain species.

INTRODUCTION

The herbicidal properties of 2-oxobenzothiazole-3(2*H*)-acetic acid derivatives were first described three decades ago (Brookes and Leafe, 1963). Since then, the 4-chloro analogue in this series, benazolin (1), has found commercial utility in combination with phenoxy herbicides for the selective control of certain broadleaf weeds in cereal crops and oilseed crops (Pass and Watt, 1974; Molberg and Ashraff, 1971). The herbicidal effects of 1 are similar to those of phenoxy herbicides with hormonal activity (Brookes and Leafe, 1963; Muhlethelar, 1968; Lush et al., 1965). The auxin-like activity of 1 has been further demonstrated by comparison with indole-3-acetic acid in a pea straight growth bioassay (Whately and Slife, 1983).

The effect of replacing the benzene ring of 1 with a heterocyclic ring on herbicidal activity has not been previously reported. In connection with a program directed toward exploring the utility of 2-(haloalkyl)-substituted pyridine substructure in designing newer herbicides, we have prepared several thiazolo[4,5-*b*]-pyridine-3(2*H*)-acetic acid derivatives represented by the general formula 2 (Figure 1). In this paper we describe the methods of synthesis and the structure–herbicidal activity correlations of compounds 2.

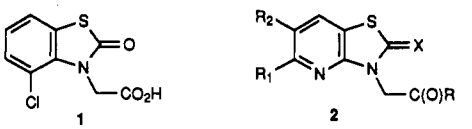

Figure 1. Structure of benazolin (1) and general formula (2, R_1 = haloalkyl, R_2 = H, Cl) of compounds in the present study.

MATERIALS AND METHODS

Chemical Section. Synthetic Methods. Melting points were determined with a Thomas-Hoover capillary melting point apparatus and are uncorrected. ^{1}H NMR spectra were recorded on either a Varian XL-300 or a Varian XL-400 spectrometer using deuteriochloroform as the solvent, unless stated otherwise; chemical shifts (δ) are given in parts per million relative to tetramethylsilane as the internal standard. Satisfactory C, H, and N combustion analysis data were obtained on all new compounds. Compounds **4a** and **4b** were prepared by acylation of ethyl vinyl ether (3) with trifluoroacetic anhydride and chlorodifluoroacetic anhydride, respectively, according to previously reported procedures (Hojo et al., 1976). Compound 7 was prepared from glycine, carbon disulfide, and chloroacetonitrile as described previously (Dovlatyan and Avetisyan, 1973). The preparation of compound **5a** from **4a** has been previously described in the literature (Heine and Ooms, 1989).

1,3-Dichloro-1,1-difluoro-4-ethoxy-3-buten-2-one (**5b**). A solution of **4b** (0.1 mol) and *N*-chlorosuccinimide (16 g, 0.12 mol) in dry acetonitrile (100 mL) was heated at reflux for 1 h and then evaporated. The residue was applied to a pad of silica gel (200 g) and eluted with ethyl acetate plus hexane (1 + 9 by volume, 1500 mL). The eluate was evaporated, and the residue was purified by distillation to afford **5b**: yield 73%; bp 97–100 °C (30 mmHg); ^{1}H NMR δ 1.35 (t, 3H, J = 8 Hz, CH_3), 4.3 (q, 2H, J = 8 Hz, OCH_2), 7.85 (s, 1H, CH).

Methyl 5-Substituted and 5,6-Disubstituted 2-Thioxothiazolo[4,5-b]pyridine-3(2H)-acetates (**8a–d**). A solution of 7 (2.04 g, 0.01 mol) and the appropriate compound 4 or 5 (0.012 mol) in tetrahydrofuran (50 mL) was stirred while piperidine (4 drops) was added. The mixture was heated at reflux for 12 h and then evaporated to dryness, and the residue was applied to a pad of silica gel (100 g). Elution with ethyl acetate plus hexane (1 + 19 by volume, 1200 mL), evaporation of the eluate, and recrystallization of the residue from diethyl ether plus hexane gave the title compounds. **8a**: yield 48%; mp 109–110 °C; ^{1}H NMR δ 3.72 (s, 3H, CO_2CH_3), 5.2 (s, 2H, CH_2), 7.52 (d, 1H, J = 8.4 Hz, Ar H), 7.88 (d, 1H, J = 8.4 Hz, Ar H). **8b**: yield 59%; mp 115–116 °C; ^{1}H NMR δ 3.7 (s, 3H, CO_2CH_3), 5.2 (s, 2H, CH_2), 7.5 (d, 1H, J = 8.4 Hz, Ar H), 7.85 (d, 1H, J = 8.4 Hz, Ar H). **8c**: yield 51%; mp 111–112 °C; ^{1}H NMR δ 3.75 (s, 3H, CO_2CH_3), 5.15 (s, 2H, CH_2), 7.88 (s, 1H, Ar H). **8d**: yield 45%; mp 117–118 °C; ^{1}H NMR δ 3.72 (s, 3H, CO_2CH_3), 5.18 (s, 2H, CH_2), 7.8 (s, 1H, Ar H).

Methyl 2-Oxo-5-(trifluoromethyl)thiazolo[4,5-b]pyridine-3(2H)-acetate (**9a**). A solution of **8a** (1.5 g, 0.005 mol) and mercuric trifluoroacetate (3.4 g, 0.008 mol) in dichloromethane (50 mL) was heated at reflux for 6 h and then filtered to remove the mercuric sulfide precipitate. The filtrate was evaporated to dryness, and the residue was partitioned between ethyl acetate (50 mL) and 3 M hydrochloric acid (50 mL). The organic layer was washed with water, dried, and evaporated. The residue was purified by chromatography on a silica gel column using ethyl acetate plus cyclohexane (1 + 10 by volume) eluent to obtain **9a**: yield 60%; mp 111–112 °C; ^{1}H NMR δ 3.75 (s, 3H, CO_2CH_3), 4.8 (s, 2H, CH_2), 7.44 (d, 1H, J = 8.4 Hz, Ar H), 7.8 (d, 1H, J = 8.4 Hz, Ar H).

Methyl 6-Chloro-2-oxo-5-(trifluoromethyl)thiazolo[4,5-b]-pyridine-3(2H)-acetate (**9b**). Treatment of **8c** with mercuric trifluoroacetate as above and chromatographic purification of the crude product gave **9b**: yield 58%; mp 136–137 °C; ^{1}H NMR δ 3.75 (s, 3H, CO_2CH_3), 4.72 (s, 2H, CH_2), 7.82 (s, 1H, Ar H).

Methyl 5-(Difluoromethyl)-2-thioxothiazolo[4,5-b]pyridine-3(2H)-acetate (**8e**). A solution of **8b** (2.8 g, 0.0086 mol) and triethylamine (15 mL) in methanol (100 mL) was hydrogenated over 5% palladium–carbon (0.4 g) in a Parr apparatus at 60 psi of hydrogen until hydrogen uptake ceased (24 h). The solution was then filtered, concentrated, and partitioned between 10% hydrochloric acid (50 mL) and ethyl acetate (100 mL). The

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organic layer was washed with water, dried, and evaporated. Recrystallization of the residue from aqueous ethanol gave **8e**: yield 76%; mp 114-115 °C; ^{1}H NMR δ 3.7 (s, 3H, CO_2CH_3), 5.2 (s, 2H, CH_2), 6.55 (t, 1H, J = 58 Hz, CHF_2), 7.5 (d, 1H, J = 8.5 Hz, Ar H), 7.85 (d, 1H, J = 8.5 Hz, Ar H).

2-Thioxo-5-(trifluoromethyl)thiazolo[4,5-b]pyridine-3(2H)-acetic Acid (**10a**). To a solution of **8a** (3 g, 0.01 mol) in methanol (50 mL) was added 2.5 M sodium hydroxide (6 mL), and the mixture was heated at reflux for 4 h. After acidification with hydrochloric acid, the mixture was evaporated to dryness and the residue was partitioned between water and ethyl acetate. The organic layer was dried and evaporated, and the residue was recrystallized from ethanol–water to obtain **10a**: yield 88%; mp 190–191 °C; ^{1}H NMR δ 5.25 (s, 2H, CH_2), 7.55 (d, 1H, J = 8.5 Hz, Ar H), 7.85 (d, 1H, J = 8.5 Hz, Ar H), 12.4 (br s, 1H, CO_2H).

5-(Chlorodifluoromethyl)-2-thioxothiazolo[4,5-b]pyridine-3(2H)-acetic Acid (**10b**). Hydrolysis of **8b** as above gave **10b**: yield 81%; mp 161–162 °C; ^{1}H NMR δ 5.25 (s, 2H, CH_2), 7.5 (d, 1H, J = 8.5 Hz, Ar H), 7.85 (d, 1H, J = 8.5 Hz, Ar H), 12.6 (br s, 1H, CO_2H).

2-Thioxo-5-(trifluoromethyl)thiazolo[4,5-b]pyridine-3(2H)-acetic Acid 2-Ethoxy-1-methyl-2-oxoethyl Ester (**11**). To a solution of **10a** (1.2 g, 0.004 mol) and ethyl 2-bromopropionate (0.9 g, 0.005 mol) in dimethylformamide (15 mL) was added anhydrous potassium carbonate (1.5 g), and the resulting slurry was stirred at room temperature for 70 h. The reaction mixture was diluted with water and extracted with ethyl acetate. The organic layer was washed with water, dried, and evaporated. Chromatographic purification of the residue on a column of silica gel using ethyl acetate plus cyclohexane (1 + 9 by volume) eluent gave **11**: yield 58%; mp 82–83 °C; ^{1}H NMR δ 1.2 (t, 3H, J = 7.8 Hz, $CO_2CH_2\mathbf{CH_3}$), 1.48 (d, 3H, J = 8 Hz, $CH\mathbf{CH_3}$), 4.12 (q, 2H, J = 7.8 Hz, $CO_2\mathbf{CH_2}CH_3$), 5.15 (q, 1H, J = 8 Hz, $\mathbf{CH}CH_3$), 5.2 (d, 1H) and 5.4 (d, 1H) (J = 16 Hz, NCH_2), 7.5 (d, 1H, J = 8.5 Hz, Ar H), 7.88 (d, 1H, J = 8.5 Hz, Ar H).

N-Methoxy-2-thioxo-5-(trifluoromethyl)thiazolo[4,5-b]pyridine-3(2H)-acetamide (**12**). A solution of **10a** (2.9 g, 0.01 mol) and thionyl chloride (10 mL) in dichloromethane (100 mL) was heated at reflux for 3 h and then evaporated to dryness. A solution of the residue in dioxane (10 mL) was slowly added to a solution of methoxyamine in dioxane [prepared by neutralizing methoxyamine hydrochloride (2 g, 0.024 mol) in dioxane (20 mL) with 2.5 M sodium hydroxide (10 mL)] at 0 °C and stirred for 5 h. The mixture was evaporated, and the residue was partitioned between water and ethyl acetate. The organic layer was washed with dilute hydrochloric acid, dried, and evaporated. Recrystallization of the residue from ethanol–water gave **12**: yield 53%; mp 178–179 °C; ^{1}H NMR (hexadeuteriodimethyl sulfoxide) δ 3.52 (s, 3H, OCH_3), 3.75 (br s, 1H, NH), 4.9 (s, 2H, CH_2), 7.85 (d, 1H, J = 8.4 Hz, Ar H), 8.45 (d, 1H, J = 8.4 Hz, Ar H).

N-Methoxy-N-methyl-2-thioxo-5-(trifluoromethyl)thiazolo[4,5-b]pyridine-3(2H)-acetamide (**13**). Successive treatment of **10a** with thionyl chloride and *O,N*-dimethylhydroxylamine as above gave **13**: yield 70%; mp 142–143 °C; ^{1}H NMR δ 3.2 (s, 3H, NCH_3), 3.85 (s, 3H, OCH3), 5.4 (s, 2H, CH_2), 7.5 (d, 1H, J = 8.4 Hz, Ar H), 7.85 (d, 1H, J = 8.4 Hz, Ar H).

Ethyl α-Methyl-2-thioxo-5-(trifluoromethyl)thiazolo[4,5-b]pyridine-3(2H)-acetate (**14**). To a suspension of DL-alanine ethyl ester hydrochloride (2.5 g, 0.016 mol) and carbon disulfide (1.4 g, 0.018 mol) in methanol (10 mL) at 0 °C was added dropwise a solution of potassium hydroxide (1.8 g, 0.032 mol) in methanol (10 mL). After the mixture was stirred for 2 h, chloroacetonitrile (1.2 g, 0.016 mol) was introduced and the stirring was continued at 0 °C for 3 h. The reaction mixture was then diluted with water (50 mL) and extracted with ethyl acetate (3 × 50 mL). The combined organic layers were washed with water, dried, and evaporated. To a solution of the residue from above in tetrahydrofuran (30 mL) was added **4a** (3.36 g, 0.02 mol) and piperidine (0.2 mL), and the mixture was heated at reflux for 12 h. The reaction mixture was then evaporated, and the residue was applied to a pad of silica gel (75 g). Elution with ethyl acetate plus hexane (1 + 19 by volume) and evaporation of the eluate gave a solid residue. Recrystallization from hexane plus diethyl ether afforded **14**: yield 26%; mp 98–99 °C; ^{1}H NMR δ 1.1 (t, 3H, J = 7.5 Hz, $CO_2CH_2\mathbf{CH_3}$), 1.62 (d, 3H, J = 8 Hz, 3H), 4.13 (q, 2H, J = 7.5 Hz, $CO_2\mathbf{CH_2}CH_3$), 6.08 (q, 1H, J = 8 Hz, NCH), 7.5 (d, 1H, J = 8 Hz, Ar H), 7.85 (d, 1H, J = 8 Hz, Ar H).

Table I. Pre-Plant-Incorporated Herbicidal Activity of Compounds 8–14 and Benazolin (1) against Crop Plants and Representative Weed Species[a]

	GR20[b] (kg/ha)		GR80[c] (kg/ha)					
compd	corn	wheat	BG	DB	VL	MG	GA	CW
8a	>11	11.0	6.4	7.5	4.9	0.4	0.7	0.9
8b	5.6	11.0	>11	>11	4.6	2.0	0.7	0.7
8c	>11	5.6	>11	7.5	>11	0.7	0.9	0.2
8d	>11	>11	>11	>11	>11	9.0	7.5	6.4
8e	>11	5.6	11.0	6.9	4.7	2.0	0.9	3.0
9a	4.7	2.2	5.6	5.2	1.1	0.7	0.8	2.2
9b	>11	5.6	6.9	>11	9.0	0.2	0.2	1.1
10a	>11	1.1	7.5	10	3.0	0.2	0.7	0.8
10b	>11	0.8	11.0	0.2	0.6	0.2	7.5	5.9
11	>11	>11	>11	>11	5.9	2.6	0.9	1.9
12	>11	5.6	>11	>11	4.4	3.4	4.6	3.4
13	>11	>11	>11	>11	>11	>11	>11	>11
14	>11	>11	>11	>11	>11	>11	>11	>11
1	>11	2.0	5.0	8.6	0.8	0.9	0.5	0.1

[a] Key to the weed species in this study: BG, barnyard grass (*E. crus-galli*); DB, downy brome (*B. tectorum*); VL, velvetleaf (*A. theophrasti*); MG, morning glory (*Ipomea* spp.); GA, cleavers (*G. aparine*); CW, common chickweed (*S. media*). [b] GR20, dose of herbicide in kg/ha causing 20% injury. [c] GR80, dose of herbicide in kg/ha causing 80% injury.

Biology Section. Determination of Herbicidal Activity. All of the synthetic compounds described above were evaluated in pre-plant-incorporated and postemergence herbicidal assays. The evaluations included two crops, corn and wheat, two monocotyledonous species: barnyardgrass (*Echinochloa crus-galli*) and downy brome (*Bromus tectorum*), and four dicotyledonous species, velvetleaf (*Abutilon theophrasti*), morning glory (*Ipomoea* spp.), cleavers (*Galium aparine*), and common chickweed (*Stellaria media*).

Pre-Plant-Incorporated Herbicidal Activity (Table I). A Dupo silt loam soil containing less than 2% organic matter was placed in aluminum pans and compacted with furrows to a depth of 1.27 cm from the top of the pan. Seeds of plant species described above were placed in the furrows and covered with soil which was premixed with a known amount of the test compound dissolved in acetone. The amount of applied herbicide corresponded to application rates that ranged from 0.07 to 11.2 kg/ha. The pans were subsequently overhead-irrigated with approximately 0.5 cm of water, and all subsequent moisture was supplied through subirrigation. At 27–30 days after treatment, all pans were rated visually against an untreated control with 0 and 100% representing no injury and complete plant death, respectively. The data were converted to GR20s for crops and GR80s for weeds, which are the rates of herbicide (kilograms per hectare) that cause 20% crop injury and 80% weed injury, respectively.

Postemergence Herbicidal Activity (Table II). The pans, species, and method of seeding were the same as above. The soil used to cover the seeds consisted of a 1:1 mixture of the Dupo silt loam and readiearth. All pans were watered exclusively by subirrigation. When plants reached the 1–3 true leaf growth stage, an acetone plus water (1 + 1 by volume) solution containing a desired amount of the test compound and 0.1% by volume of AG-98 surfactant was applied to the foliage. The amount of applied herbicide corresponded to application rates that ranged from 0.07 to 11.2 kg/ha. All treatments were rated and all data reported in the same manner as described for pre-plant-incorporated activity.

RESULTS AND DISCUSSION

Chemical Studies. The intermediates required for the construction of the thiazolo[4,5-*b*]pyridine ring system were prepared as shown in Figure 2. Ethyl vinyl ether (**3**) was acylated with trifluoroacetic anhydride and chlorodifluoroacetic anhydride to give β-ethoxy enones **4a** and **4b**, respectively. Chlorination of **4a** and **4b** with *N*-chlo-

Table II. Postemergence Herbicidal Activity of Compounds 8–14 and Benazolin (1) against Crop Plants and Representative Weed Species[a]

	GR20[b] (kg/ha)		GR80[c] (kg/ha)					
compd	corn	wheat	BG	DB	VL	MG	GA	CW
8a	>11	11.0	>11	>11	5.6	1.1	1.1	0.3
8b	>11	11.0	>11	>11	9.0	11.0	7.5	11.0
8c	>11	>11	>11	>11	7.5	5.6	3.7	1.1
8d	>11	>11	>11	>11	>11	>11	>11	>11
8e	>11	7.5	>11	>11	6.9	1.1	7.5	>11
9a	>11	11	>11	>11	4.1	0.5	4.5	3.7
9b	>11	7.5	>11	>11	>11	0.2	8.2	4.1
10a	>11	>11	>11	>11	5.9	1.1	1.1	6.4
10b	>11	9.5	>11	>11	6.4	4.5	2.4	4.7
11	>11	>11	>11	>11	1.1	0.3	7.5	4.7
12	>11	>11	>11	>11	>11	>11	>11	>11
13	>11	>11	>11	>11	>11	>11	>11	>11
14	>11	>11	>11	>11	>11	>11	>11	>11
1	>11	>11	>11	>11	0.9	5.6	0.1	0.3

[a] Key to the weed species in this study: BG, barnyard grass (*E. crus-galli*); DB, downy brome (*B. tectorum*); VL, velvetleaf (*A. theophrasti*); MG, morning glory (*ipomea* spp.); GA, cleavers (*G. aparine*); CW, common chickweed (*S. media*). [b] GR20, dose of herbidie in kg/ha causing 20% injury. [c] GR80, dose of herbicide in kg/ha causing 80% injury.

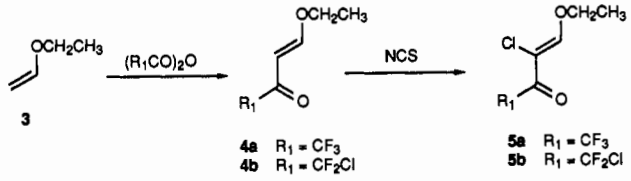

Figure 2. Preparation of β-ethoxy enone intermediates **4a,b** and **5a,b**.

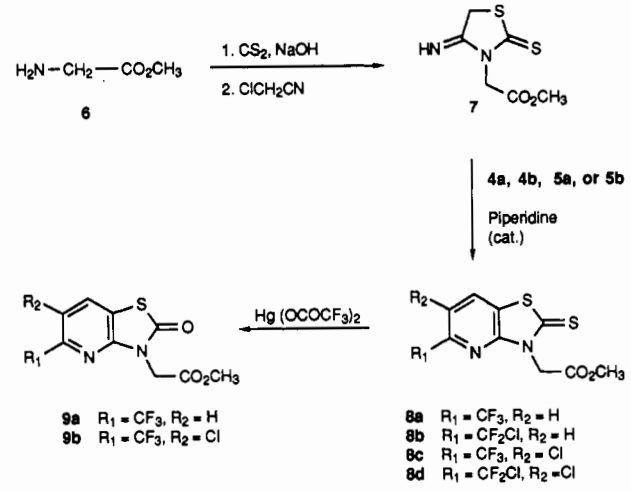

Figure 3. Synthesis of thiazolo[4,5-b]pyridine-3(2H)-acetates **8a–d** and **9a,b**.

rosuccinimide provided the corresponding chloro derivatives **5a** and **5b**, respectively.

The synthesis of 2-thioxothiazolo[4,5-b]pyridine-3-(2H)-acetate derivatives **8a–d** entailed a novel condensation reaction of the β-ethoxy enones **4a,b** and **5a,b** with methyl 4-imino-2-thioxo-3-thiazolidineacetate (**7**) in the presence of a catalytic amount of piperidine (Figure 3). Although the condensation can, in theory, lead to two different regioisomers with the haloalkyl group in either the 5- or 7-position of the thiazolopyridine ring, a single isomer was produced in each case. Selective INADEQUATE NMR experiments (Berger, 1988) on products **8a–d** indicated that the carbon bearing the haloalkyl group was coupled to only one other carbon in each case, thereby establishing the 5-position of the haloalkyl group (see supplementary material). The 2-oxothiazolo[4,5-b]pyridine-3-(2H)-acetates **9a** and **9b** were prepared from compounds **8a** and **8c**, respectively, by treatment with mercuric trifluoroacetate.

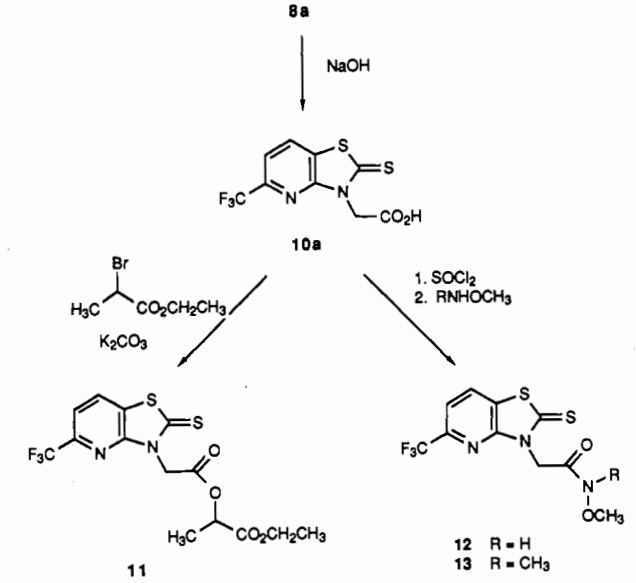

Figure 4. Derivatization of the carboxylate group in **8a**: preparation of acid **10a**, lactate ester **11**, and alkoxyamides **12** and **13**.

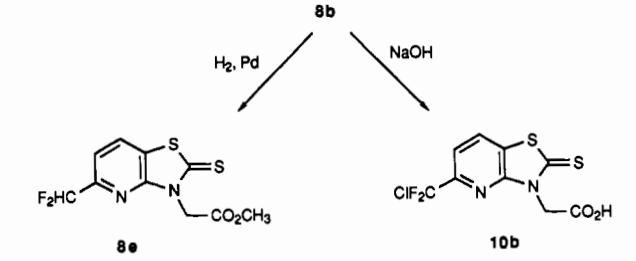

Figure 5. Transformations of compound **8b**: preparation of acid **10b** and difluoromethyl derivative **8e**.

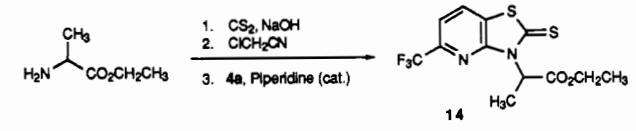

Figure 6. Preparation of the α-methyl-substituted 2-thioxothiazolo[4,5-b]pyridine-3-(2H)-acetate derivative **14**.

The carboxylic ester group of **8a** was shown to be amenable to further transformations as depicted in Figure 4. Thus, compound **8a** was hydrolyzed to the corresponding acid **10a** by treatment with sodium hydroxide. Alkylation of **10a** with ethyl 2-bromopropionate in the presence of potassium carbonate gave the lactate ester **11**. Alternatively, the carboxylic acid group of **10a** was first converted to the acid chloride by reaction with excess thionyl chloride and the acid chloride was treated with methoxyamine or *N,O*-dimethylhydroxylamine to obtain amides **12** and **13**, respectively.

The chlorodifluoromethyl group of compound **8b** was readily hydrogenated to produce the 5-(difluoromethyl)-thiazolo[4,5-b]pyridine derivative **8e** (Figure 5). In addition, **8b** was hydrolyzed to the corresponding acid **10b** by reaction with sodium hydroxide.

Finally, an α-methyl-substituted thiazolo[4,5-b]pyridine-3-(2H)-acetate derivative **14** was synthesized (Figure 6) starting from DL-alanine ethyl ester and utilizing a similar sequence of reactions as described in Figure 3.

Biological Evaluations. Tables I and II provide the herbicidal activity data from the pre-plant-incorporated

and postemergence assays, respectively. In general, the compounds were more active on dicotyledonous than monocotyledonous species with the difference being most apparent in postemergence evaluations. All of the active compounds exhibited auxin-like herbicidal symptoms characterized by epinastic response and formative action. Shoot apex inhibition was also noted in several postemergence evaluations.

Most compounds showed a high degree of selectivity in corn in both pre-plant-incorporated and postemergence assays. Selectivity in wheat was high in post-emergence tests and moderate in pre-plant-incorporated tests.

Three general correlations of structure and activity are summarized as follows: (1) A dramatic difference in activity against weeds was observed between compound **8a** and the corresponding α-methyl analogue **14**. The former had some activity against most dicotyledonous weeds, whereas the latter was virtually inactive, indicating a large variability of activity with respect to the α-substituent. (2) The methoxyamide **12** had some activity in pre-plant-incorporated assays and no activity in postemergence assays. The corresponding *N*-methyl derivative **13** was inactive in both assays. (3) Among the carboxylic esters in the 2-thioxo series, compound **8d** (5-CF_2Cl, 6-Cl) was less active than compounds **8a** (5-CF_3, 6-H), **8b** (5-CF_2Cl, 6-H), **8c** (5-CF_3, 6-Cl), and **8e** (5-CF_2H, 6-H). Thus, the herbicidal activity was critically dependent on the combined effect of the 5- and 6-position substituents.

Further correlations can be made between structure and activity on specific weeds. Thus, in pre-plant-incorporated tests, *G. aparine* and *Ipomoea* spp. were the most susceptible species (Table I). The activity on *G. aparine* depended critically on the 2- and 6-position substituents. In this case, the 2-oxo-6-chloro compound **9b** was significantly more active than the 2-oxo-6-H compound **9a**, the 2-thioxo-6-H compounds **8a,b,e**, **10a**, **11**, and the 2-thioxo-6-chloro compound **8c**. On *Ipomoea* spp. compound **9b** and the acids **10a** and **10b** were most active. Compound **9b** was more active than benazolin (**1**) on both species. On the remaining dicotyledonous weed species, benazolin was generally more active than the compounds in this study.

In postemergence tests, *Ipomoea* spp. was the most sensitive species (Table II). Again, compound **9b** was the most active, closely followed by the lactate ester **11**. Compound **9b** was also substantially more active than benazolin. On all other species, benazolin had higher activity than the analogues in this study.

Conclusion. The results from this study demonstrated that replacing the benzene ring of benazolin (**1**) with a pyridine ring did not alter the general nature and the spectrum of activity. However, the levels of activity varied significantly depending on the species. Structure–activity correlations of several compounds of the general formula **2** revealed that a combination of 2-oxo and 6-chloro substituents resulted in higher activity than **1** in certain dicotyledonous weeds.

ACKNOWLEDGMENT

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Supplementary Material Available: Selective INADEQUATE NMR spectra (Figure 7a–e) of compound **8b** and interpretation (4 pages). Ordering information is given on any current masthead page.

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