Atrazine Metabolism in Resistant Corn and Sorghum

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Abstract. The metabolism of 2-chloro-4-ethylamino-6-isopropylamino-s-triazine (atrazine) in the resistant species, corn (Zea mays L.) and sorghum (Sorghum vulgare Pers.) was not the same. In corn, atrazine was metabolized via both the 2-hydroxylation and N-dealkylation pathways while sorghum metabolized atrazine via the N-dealkylation pathway. Atrazine metabolism in corn yielded the metabolites, 2-hydroxy-4-ethylamino-6-isopropylamino-s-triazine (hydroxatrazine), 2-hydroxy-4-amino-6-isopropylamino-s-triazine (hydroxycompound I), and 2-hydroxy-4-amino-6-ethylamino-s-triazine (hydroxycompound II). None of these hydroxylated derivatives appeared as metabolites of atrazine in sorghum.

Hydroxylated compounds I and II were formed in 2 ways in corn: (1) by benzoaxinone-catalyzed hydrolysis of 2-chloro-4-amino-6-isopropylamino-s-triazine (compound I) and 2-chloro-4-amino-6-ethylamino-s-triazine (compound II) that were formed by N-dealkylation of atrazine and (2) by N-dealkylation of hydroxatrazine, the major atrazine metabolite in corn. The interaction of the 2-hydroxylation and N-dealkylation pathways in corn results in the formation of the 3 hydroxylated non-phytotoxic derivatives of atrazine.

Metabolism of 2-chloro-4-ethylamino-6-isopropylamino-s-triazine (atrazine) in higher plants was shown to be an important factor in herbicidal selectivity. Detoxication of atrazine was reported to occur via the 2-hydroxylation and N-dealkylation pathways in higher plants (12). Corn is resistant to atrazine and 2-chloro-4,6-bis(ethylamino)-s-triazine (simazine) largely because of its ability to convert the 2 herbicides rapidly to non-phytotoxic, 2-hydroxy-4-ethylamino-6-isopropylamino-s-triazine (hydroxatrazine), and 2-hydroxy-4,6-bis(ethylamino)-s-triazine (hydroxysimazine) (1, 2, 5, 10, 12). The conversion of the 2-chlorotriazines to their 2-hydroxy derivatives is catalyzed non-enzymatically by a cyclic hydroxamate, 2,4-dihydroxy-3-keto-7-methoxy-1,4-benzoazinone (benoxazinone) present in corn plants (1, 5, 9). The hydroxylation reaction appears to be correlated with the presence of benoxazinone in different species (4, 12).

N-Dealkylation of atrazine occurred in higher plants to form 2-chloro-4-amino-6-isopropylamino-s-triazine (compound I) and 2-chloro-4-amino-6-ethylamino-s-triazine (compound II) (12, 13, 14). In resistant sorghum, only the N-dealkylation pathway was reported to be active, but in corn both hydroxylation and N-dealkylation pathways were active. Autoradiographic evidence indicated that after a 48-hr atrazine treatment period, corn and sorghum yielded at least 1 common water-soluble metabolite of atrazine, but corn produced 2 other metabolites, neither of which was hydroxatrazine (12).

Hydroxylation of compounds I and II to form hydroxycompounds I and II (fig 1) is possible in benoxazinone-containing corn, but not in sorghum. N-Dealkylation of hydroxatrazine (fig 1) could also occur in corn to give hydroxycompounds I and II. Such a reaction would not occur in sorghum since atrazine is not converted to hydroxatrazine in sorghum. This investigation was undertaken to show that in corn the reactions mentioned above were responsible for producing 2 unidentified metabolites which were hypothesized to be hydroxycompounds I and II. A discussion is presented on the interaction of the hydroxylation and N-dealkylation pathways which results in the formation of the water-soluble metabolites in corn.

Materials and Methods

Plant Material. Seeds of corn (Zea mays L. North Dakota KE 47101) and sorghum (Sorghum vulgare Pers. var. North Dakota 104) were germinated in vermiculite for 6 days as previously described (12). The young corn and sorghum seedlings were removed from vermiculite and grown in continuously aerated half-strength Hoagland's solution in the greenhouse. Selected plants were transferred to a controlled-environment room for all treatments.

Atrazine Metabolism in Plants. Uniformly ring-labeled atrazine-14C (specific activity 7.8 µc per mg) was purified as previously described (13) and used for treatment of corn and sorghum plants. The roots of the experimental plants were immersed in an aqueous solution of atrazine-14C added to 200 ml of half-strength Hoagland's solution. Plants were treated for a 48-hr period in a controlled-environment room with a 12-hr photoperiod, 27 ± 2° day temperature and 20 ± 2° night temperature, 40 ±
5% relative humidity and a light intensity of 1600 ft-c.

Hydroxyatrazine Metabolism in Plants. Uniformly ring-labeled hydroxyatrazine-$^{14}$C (specific activity 4.6 μC per mg) was purified by thin-layer chromatography on 250 μ, silica-gel HF plate, using n-butanol:acetic acid:water (120:30:50 v/v/v) as the developing solvent. Radiocarbon assay of the purified hydroxyatrazine-$^{14}$C showed less than 1.0% of the total radioactivity present as impurities. Corn and sorghum plants were treated with an aqueous solution of hydroxyatrazine-$^{14}$C in the same manner as described above for atrazine-$^{14}$C treatment.

Plant Extraction and Assay for $^{14}$C Activity. At the end of the 48-hr period of exposure to atrazine-$^{14}$C or hydroxyatrazine-$^{14}$C, the fresh root and shoot tissues were extracted separately. The atrazine-$^{14}$C-treated tissues were extracted with 95% methanol and the hydroxyatrazine-$^{14}$C-treated plants were extracted with 80% methanol. The methanol in the extracts was removed under vacuum to give an aqueous solution which was purified as previously reported (12,14). Partitioning between chloroform and water was performed on extracts from atrazine-$^{14}$C-treated plants to remove atrazine and its chloroform-soluble metabolites from the purified aqueous extract. Partitioning between chloroform and water was excluded on extracts from hydroxyatrazine-$^{14}$C treated plants since hydroxyatrazine and its metabolites are predominantly water soluble. The $^{14}$C activity in chloroform-soluble and water-soluble compounds was determined by liquid scintillation counting (14).

The water-soluble radioactive metabolites of atrazine-$^{14}$C and hydroxyatrazine-$^{14}$C were purified by cation exchange chromatography and separated by thin-layer chromatography for detection and identification as previously reported (12). Quantitative assay of radioactive compounds from thin-layer plates was made by carefully removing the compounds from the plate and counting by gel scintillation counting (13). The radiocarbon remaining in methanol-insoluble plant residue was measured by dry combustion in oxygen in Schoniger flasks as previously described (12).

Crude Corn Extract and Benzoazinone Incubation of Chloroform-Soluble Triazines. A crude, 90% acetone-precipitated, protein-free, corn extract was prepared in a manner similar to that of Castelfranco et al. (1). Corn seeds were germinated between paper towels in the dark for 4 days and placed in the greenhouse for another 24 hr. The coleoptiles and young shoots were excised and used in preparing the crude, protein-free corn extract for incubation experiments. A 4 mM benzoazinone solution in 0.2 M phosphate buffer, pH 7.0, was also used in incubation experiments.

Identification of Hydroxylated Metabolites. Authentic hydroxyatrazine was obtained from a commercial source. Authentic 2-hydroxy-4-amino-6-isopropylamino-s-triazine (hydroxycompound I, m.p. 166-169°) and 2-hydroxy-4-amino-6-ethylamino-s-triazine (hydroxycompound II, m.p. 201-204°) were prepared by HCl hydrolysis of compounds I and II as previously reported (1,12). Compounds I and II were prepared by the method of Thurston et al. for 2-chloro-4-amino-6-alkylamino-s-triazine (15). [Compound I-m.p. 135-137°, reported m.p. (3) 134.5-136.5°; compound II-m.p. 175-179°, reported m.p. (8) 177-179°].

Table I. Recovery of $^{14}$C Activity From Hydroxyatrazine-$^{14}$C-Treated Plants

<table>
<thead>
<tr>
<th>Species</th>
<th>$^{14}$C Activity recovered</th>
<th>Nutrient solution</th>
<th>Plants</th>
<th>Total recovered</th>
<th>$^{14}$C Activity Absorbed by plants</th>
<th>dpm</th>
<th>%</th>
<th>dpm/g fr wt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sorghum</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>dpm</td>
<td>dpm</td>
<td>%</td>
<td>%</td>
<td>dpm/g fr wt</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sorghum</td>
<td>445,075</td>
<td>66,027</td>
<td>89.7</td>
<td>12.9</td>
<td>1699</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corn</td>
<td>451,535</td>
<td>54,651</td>
<td>88.8</td>
<td>10.8</td>
<td>1750</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 Calculated on combined fresh weights of roots and shoots.

Table II. Distribution of $^{14}$C Activity in Plants Treated With Hydroxyatrazine-$^{14}$C

<table>
<thead>
<tr>
<th>Species</th>
<th>$^{14}$C Activity in entire plant</th>
<th>Methanol-soluble $^{14}$C activity</th>
<th>Methanol-insoluble residue</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Shoot %</td>
<td>Root %</td>
<td>Shoot %</td>
</tr>
<tr>
<td>Sorghum</td>
<td>43.4</td>
<td>56.6</td>
<td>97.0</td>
</tr>
<tr>
<td>Corn</td>
<td>35.6</td>
<td>64.4</td>
<td>97.0</td>
</tr>
</tbody>
</table>

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Results

Atrazine Metabolism in Plants. The results on absorption, translocation, and metabolism of atrazine-14C in corn and sorghum were similar to results reported previously (12). Therefore, the results are not presented in this paper, but reference is made to the published data.

Absorption and Translocation of Hydroxylated Atrazine-14C. There was no significant difference between corn and sorghum in the absorption of hydroxylated atrazine-14C from the nutrient solution (table I). Within 48 hr, 12.9% and 10.8% of the applied hydroxylated atrazine-14C in solution were absorbed by sorghum and corn, respectively. The distribution of 14C activity in the plant indicated that 56.6% and 64.4% of the radioactivity remained in the roots of sorghum and corn, respectively (table II). In atrazine-14C-treated plants, the radioactivity remaining in the roots of plants was reported to be 64% in corn and only 28% in sorghum (12). The low accumulation of 14C activity in roots of atrazine-14C-treated plants was also reported in soybean, pea, and wheat (12). The results in table II indicate that hydroxylated atrazine may not be as readily translocated from the roots to the shoots as was reported for atrazine. The retention of 14C activity in sorghum and corn roots did not appear to be due to metabolism and fixation of hydroxylated atrazine-14C into insoluble plant residue (table II). The methanol-insoluble residue accounted for only a small part of the total radiocarbon present in the roots.

In corn, the 14C activity remaining in the root was greater than the activity found in the shoots when this species was treated with either atrazine-14C (12) or hydroxylated atrazine-14C. Corn is known to convert atrazine to hydroxyatrazine very rapidly. Therefore, the distribution pattern of 14C activity in atrazine-14C-treated corn plants may be expected to be very similar to hydroxyatrazine-14C-treated plants. In sorghum atrazine-14C was not converted to hydroxyatrazine-14C (fig 2) (see also reference 12). Therefore, the difference in root accumulation of radiocarbon in atrazine-14C- and hydroxyatrazine-14C-treated sorghum plants is not unexpected.

Metabolism of Hydroxylated Atrazine. Hydroxylated atrazine, and hydroxylated products I and II, were identified by thin-layer chromatography. The Rf values obtained by multiple chromatography, as described previously (12), and 2 other solvent systems are given in table III. The 3 hydroxylated derivatives (fig 1) are hydrolysis products of the herbicide atrazine, and 2 of its N-dealkylated metabolites.

![Fig. 1. Interaction of benzoxazinone-catalyzed hydrolysis and N-dealkylation reactions in corn to give 3 hydroxylated, completely non-phytotoxic derivatives of atrazine.](image1)

![Fig. 2. Water-soluble metabolites extracted from roots of corn (no. 2) and sorghum (no. 3) plants treated with hydroxylated atrazine-14C. No. 4 represents water-soluble metabolites present in shoots of sorghum plants treated with atrazine-14C for a 96-hr period. No. 1—authentic hydroxyatrazine-14C, O—origin, A—hydroxycompound II, B—hydroxycompound I, C—hydroxyatrazine. Hydroxycompound II was present in low concentration and its spots are outlined in this photograph. The thin-layer chromatogram was developed by multiple chromatography (12).](image2)
Table III. Rf Values for Hydroxyatrazine, Hydroxycompound I, and Hydroxycompound II

The Rf values were determined after co-chromatography of non-radioactive authentic compounds and 14C-labeled metabolites of hydroxyatrazine-14C in roots of sorghum and corn plants. Compounds were separated on 250 μ silica gel HF thin-layer plates with 3 different solvent systems. Non-radioactive compounds were detected under UV light and radioactive compounds were detected by autoradiography.

<table>
<thead>
<tr>
<th>Compound</th>
<th>Migration values</th>
<th>Solvent A1</th>
<th>Solvent B2</th>
<th>Solvent C3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rf</td>
<td>Rf</td>
<td>Rf</td>
<td></td>
</tr>
<tr>
<td>Hydroxyatrazine</td>
<td>0.73</td>
<td>0.19</td>
<td>0.28</td>
<td></td>
</tr>
<tr>
<td>Hydroxycompound I</td>
<td>0.65</td>
<td>0.11</td>
<td>0.22</td>
<td></td>
</tr>
<tr>
<td>Hydroxycompound II</td>
<td>0.53</td>
<td>0.06</td>
<td>0.16</td>
<td></td>
</tr>
</tbody>
</table>

1 Multiple chromatography system (12) (best resolution obtained with this system).
2 Benzene:acetic acid:water (50:50:2 v/v/v).
3 n-Butanol:benzene:acetic acid (2:1:10 v/v/v).

14C compounds I and II. The chlorotriazine derivatives, compounds I and II, were reported to be present in several species, including sorghum and corn (12). N-Dealkylation of either N-alkyl groups of hydroxyatrazine, a predominant metabolite of atrazine in corn, gives the same compounds obtained when compounds I and II are hydrolyzed.

Metabolism of hydroxyatrazine in corn and sorghum indicated that N-dealkylation of the compound occurred in both species to give hydroxycompounds I and II (fig 2). The quantitative data on the radiocarbon found in the roots indicated that N-dealkylation of hydroxyatrazine was much more active in sorghum than in corn (table IV). In sorghum 43.2% of the 14C activity was present as hydroxycompound I as compared to 10.7% in corn. Hydroxycompound II accounted for only 6.5% in sorghum and 2.6% in corn. N-Dealkylation of hydroxyatrazine in corn appears to occur slowly since 76.1% of the 14C activity was still present as unchanged hydroxyatrazine after 48 hr. N-Dealkylation of atrazine in sorghum occurred very readily and was reported to give 1.8 times as much of compound I than of compound II. In corn only 1% of the 14C activity was reported to be present as the dealkylated metabolites (12). The results of this investigation revealed that the relative N-dealkylation activities between sorghum and corn seems to be applicable to hydroxyatrazine as well as atrazine.

The water-soluble metabolites of atrazine-14C formed in sorghum plants were distinctly different from metabolites formed when this species was treated with hydroxyatrazine-14C (fig 2). The water-soluble metabolites of atrazine-14C with Rf values of 0.29, 0.24, and 0.20 (developed by multiple chromatography) were previously detected in sorghum (12). Hydroxycompounds I and II were present as metabolites in sorghum only when this species was treated with hydroxyatrazine-14C, but not when treated with atrazine-14C (fig 2). However, in corn hydroxyatrazine and hydroxycompounds I and II were detected when this species was treated with either atrazine-14C or hydroxyatrazine-14C (fig 2) (see also fig 4 in reference 12).

It was previously concluded that the metabolism of atrazine in sorghum did not proceed via the hydroxylatrazine pathway in which hydroxyatrazine is an intermediate since this compound was not detected in atrazine-treated sorghum plants (12). The results of this investigation also indicated that the N-dealkylation reaction is not specific for substitution of chlorine or the hydroxyl group in the 2-position of the triazine ring. Both corn and sorghum were found to dealkylate atrazine (12) and hydroxyatrazine (fig 2).

Crude Corn Extract and Benzoxazinone Incubation of Triazine Compounds. Compounds I and II were readily detected in shoots of sorghum plants treated with atrazine-14C for a 48-hr period. An assay of the chloroform-soluble fraction of radiocarbon in the treated plants indicated that 62% of the 14C activity was unchanged atrazine, 27% was compounds I and II, and 11% was unidentified compounds. This agreed with previously reported results (12).

Table IV. Distribution of Total 14C Activity in Roots of Sorghum and Corn Plants Treated With Hydroxyatrazine-14C

The water-soluble compounds were purified by cation exchange chromatography and radioactive compounds were spotted on 250 μ silica gel HF thin-layer plate and developed by multiple chromatography (12). The radioactive areas corresponding to hydroxyatrazine and its metabolites were detected by autoradiography. These areas were removed and 14C activity determined by gel scintillation counting.

<table>
<thead>
<tr>
<th>Species</th>
<th>Methanol-insoluble residue %</th>
<th>Unchanged OH-atrazine %</th>
<th>OH-compound I %</th>
<th>OH-compound II %</th>
<th>Unidentified %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sorghum</td>
<td>5.7</td>
<td>39.6</td>
<td>43.2</td>
<td>6.3</td>
<td>5.0</td>
</tr>
<tr>
<td>Corn</td>
<td>4.2</td>
<td>76.1</td>
<td>10.7</td>
<td>2.6</td>
<td>6.4</td>
</tr>
</tbody>
</table>
Authentic atrazine-\(^{14}\)C and the chloroform-soluble fraction of the sorghum extract described above were incubated in the crude corn extract and benzoxazinone solutions. The chloroform-soluble compounds were converted to water-soluble compounds in the crude corn extract (table V). Incubation in a 4 mM benzoxazinone solution also showed the same conversion of the chlorotriazines to their hydroxy derivatives. However, the rate of conversion was much less than the rate in crude corn extract. Thin-layer chromatography of the water-soluble derivatives formed during the crude corn extract incubation period indicated that atrazine was converted to hydroxyatrazine, and compounds I and II were converted to hydroxycompounds I and II (fig 3). The non-enzymatic conversion of atrazine to hydroxyatrazine by the protein-free, crude corn extract was demonstrated previously (1,5,9). Apparently, the monodealkylated compounds I and II, as well as atrazine, were readily converted to their hydroxylated derivatives in the crude corn extract. The water-soluble derivatives formed during the crude corn extract incubation of the sorghum extract (fig 3) were the same as the water-soluble metabolites found in sorghum plants treated with hydroxyatrazine-\(^{14}\)C (fig 2). Although the compounds are alike, the 3 hydroxylated derivatives in figure 3 were formed by an apparent benzoxazinone-catalyzed hydrolysis of atrazine and compounds I and II, whereas hydroxycompounds I and II in figure 2 were formed by N-dealkylation of hydroxyatrazine introduced into the sorghum plant via the root.

The results indicated that benzoxazinone, which is present in high concentrations in corn, readily catalyzed the hydrolysis of 2-chloro-s-triazines to their 2-hydroxy analogs. The alkyl substitution of the amine groups in the 4- and 6-positions of the s-triazine ring did not seem to interfere with the non-enzymatic hydrolysis in the 2-position.

### Discussion and Conclusion

Hydroxycompound II was reported to be present in simazine-\(^{14}\)C-treated *Coix lacryma-jobi* L. (6) and corn (7). Both species contain large amounts of benzoxazinone (4). Hydroxycompounds I and II were reported to be present in atrazine-\(^{14}\)C-treated corn (11). The evidence indicates that the formation of hydroxylated derivatives of chlorotriazines may be limited to species which contain benzoxazinone.

Benzoxazinone was not found to be present in sorghum (4,12). The results of this investigation indicate that atrazine metabolism in corn and sorghum is not the same. None of the hydroxylated derivatives appeared in atrazine-\(^{14}\)C-treated sorghum while all 3 hydroxylated derivatives appeared in corn treated with either atrazine-\(^{14}\)C or hydroxyatrazine-\(^{14}\)C. The results of this investigation agree with the previous conclusion that sorghum metabolized atrazine via the N-dealkylation pathway in which no hydroxylated intermediates have been identified. In corn both the N-dealkylation and hydroxylation pathways were reported to be active (12).

N-Dealkylation of atrazine, resulting in the formation of less phytotoxic compounds I and II, occurred readily in sorghum and to a lesser extent in corn (12). The results in figure 3 and table V indicated that hydrolysis of compounds I and II to hydroxycompounds I and II occurred very readily if benzoxazinone was present, as in corn. The N-dealkylation reaction was also found to be non-specific as to the substitution in the 2-position of the s-triazine ring. Figure 2 showed clearly that N-dealkylation of hydroxyatrazine, a predominant metabolite of atrazine in corn (1,2,5,10,12), occurred in corn as well as in sorghum. The results indicate that sorghum will dealkylate hydroxyatrazine as well as atrazine if hydroxyatrazine is present

### Table V. Incubation of Atrazine-\(^{14}\)C and Its Chloroform-soluble Metabolites From Sorghum in a Protein-free, Crude Corn Extract

Chloroform-soluble radioactive compounds from shoots of atrazine-\(^{14}\)C-treated sorghum plants and authentic atrazine-\(^{14}\)C were incubated in a 90 % acetone-precipitated, crude corn extract. A methanol solution containing a known amount of radioactivity was evaporated to dryness in a test tube. One ml of crude corn extract was added to the test tube and the mixture was incubated at 35° for 92 hr. At the end of the incubation period, analysis for atrazine-\(^{14}\)C and its derivatives in the incubation mixture was performed in the same manner as for plant extracts.

<table>
<thead>
<tr>
<th>Substrate</th>
<th>Chloroform-soluble</th>
<th>Distribution of (^{14})C activity after incubation</th>
<th>Metabolites in water-soluble fraction</th>
<th>OH-atrazine</th>
<th>OH-compound I</th>
<th>OH-compound II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atrazine(^1)</td>
<td>2.6</td>
<td>97.4</td>
<td>100</td>
<td>%</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>Sorghum extract(^2)</td>
<td>16.0</td>
<td>84.0</td>
<td>61.4</td>
<td>22.2</td>
<td>16.4</td>
<td></td>
</tr>
<tr>
<td>Sorghum extract (control)(^3)</td>
<td>99.7</td>
<td>0.3</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td></td>
</tr>
</tbody>
</table>

1. Atrazine is 100 % chloroform-soluble at the concentration used.
2. Sorghum extract incubated was the chloroform-soluble fraction of shoot extract from sorghum plants treated with atrazine-\(^{14}\)C for 48 hr. The chloroform-soluble fraction contained atrazine-\(^{14}\)C and radioactive compounds I and II.
3. Sorghum extract (described above) incubated in distilled water.
Fig. 3. Water-soluble compounds formed by incubation of chloroform-soluble s-triazine compounds in protein-free, crude corn extract. No. 1—derivatives formed by incubation of chloroform-soluble compounds extracted from shoots of sorghum plants treated with atrazine-14C (includes atrazine and compounds I and II), no. 2—derivatives formed by incubation of authentic atrazine-14C, no. 3—water-soluble metabolites extracted from shoots of sorghum plants treated with atrazine-14C (same sample as no. 4 in fig 2), no. 4—authentic hydroxyatrazine-14C, O—origin, A—hydroxycompound II, B—hydroxycompound I, C—hydroxyatrazine. The thin-layer chromatogram was developed as in figure 2.

N-Dealkylation in corn is apparently less active than in sorghum (fig 2, table IV) (see also reference 12), but this reaction interacts with benzoazinone-catalyzed hydrolysis of chlorotriazines to give 2 non-phytotoxic metabolites, hydroxylcompounds I and II (fig 1).

Acknowledgments

The author gratefully acknowledges the technical assistance of Mrs. Helen Baumler. Compounds I and II and hydroxylcompounds I and II were provided by Dr. F. Tanaka and Mr. R. Wien. Both labeled and non-labeled atrazine and hydroxyatrazine were provided by Geigy Chemical Corporation, Ardsley, New York. Benzoazine was provided by Dr. R. H. Hamilton.

Literature Cited