It has recently been demonstrated that light dramatically enhances the toxicity of polycyclic aromatic hydrocarbons (PAHs) to the duckweed *Lemna gibba* L. G-3 (L. Ren, X.-D. Huang, B. J. McConkey, D. G. Dixon, and B. M. Greenberg, 1994, *Ecotoxicol. Environ. Saf.* 28, 160-171). To extend this research to terrestrial plants, *Brassica napus* L. (oil seed rape) seeds were germinated in the presence of three PAHs; anthracene (ANT), benzo[a]pyrene (BAP), and fluoranthene. The chemicals were applied both in intact form and following photomodification in UV-B radiation; toxicity was assessed in simulated solar radiation (SSR), a light source with a visible light:UV-A:UV-B ratio similar to that of sunlight. Germination efficiency, root and shoot growth, and chlorophyll content, measured after 6 days of exposure, were used as toxicity endpoints. Intact and photomodified PAHs had little impact on shoot fresh weight or chlorophyll content, but markedly inhibited root fresh weight, with the photomodified PAHs having greater impacts than the intact PAHs. The decline in root fresh weight was not attributable to a decline in germination frequency or delayed germination. However, the seedlings produced shorter roots in the presence of either intact or photomodified PAHs. To explore the role of actinic radiation on PAH toxicity, seedlings were incubated in SSR, visible light and darkness. Thus, intact PAHs are hazardous to terrestrial plants in the presence of light, but once the compounds are photomodified, actinic radiation is no longer an absolute requirement for phytotoxic activity.


INTRODUCTION

Polycyclic aromatic hydrocarbons (PAHs) are a group of ubiquitous environmental contaminants consisting of two or more fused benzene rings (Suess, 1976; Cook et al., 1983; Nikolaou et al., 1984). The properties of PAHs can be altered either abiotically (e.g., photochemically) or biotically (e.g., cytochrome P450-mediated monooxygenation) (Yang et al., 1976; Neff, 1979; Katz et al., 1979; Zepp and Schlottzauer, 1979; Nikolaou et al., 1984; Shimada and Nakamura, 1987; Harvey et al., 1988; Huang et al., 1993; Ren et al., 1994). Photochemical activation occurs when the extensive π-orbital systems of PAHs absorb light in the ultraviolet-B (UV-B: 290–320 nm) and/or the ultraviolet-A (UV-A: 320–400 nm) regions of the solar spectrum (Suess, 1976; Cook et al., 1983; Nikolaou et al., 1984; Huang et al., 1993; Ren et al., 1994). The compounds are reactive following photonic absorbance, which can result in photomodification of the PAH, defined here as photooxidation and/or photolysis; the process is rapid under environmentally relevant levels of actinic radiation (Katz et al., 1979; Zepp and Schlottzauer, 1979; Nikolaou et al., 1984; Huang et al., 1993, 1995; Ren et al., 1994). Moreover, PAHs have high quantum yields for triplet-state formation and are active type II photosensitizers (Morgan et al., 1977; Newsted and Giesy, 1987; Schoeny et al., 1988; Foote, 1991). As such, they are highly efficient at promoting the formation of biologically damaging singlet oxygen (Foote, 1991) in the presence of light.

It has been demonstrated that the toxicity of PAHs to microbes, animals, and aquatic plants is enhanced by actinic radiation (Oris and Giesy, 1987; Newsted and Giesy, 1987; Huang et al., 1993; Ankley et al., 1994; Ren et al., 1994). Recent work with the higher aquatic plant *Lemna gibba* (a duckweed) has demonstrated that PAHs are photomodified by actinic radiation to a complex, unidentified mixture of photoproducts that are more toxic than the parent compounds (Huang et al., 1993; Ren et al., 1994). For all species tested, except *L. gibba*, the relative contributions to toxicity of PAHs applied in intact form and photomodified form have not been evaluated. Furthermore, the toxicity of PAHs to terrestrial plant species has not yet been explored.

Terrestrial plants are subjected to pollutants in a variety of ways, including contact with contaminated water. For instance, rainwater carries environmental contaminants including PAHs, as does irrigation water from exposed lakes.
and ponds (Suess, 1976; Basu and Saxena, 1978; Neff, 1979; Cook et al., 1983; Nikolau et al., 1984; Eadie, 1984). To further examine the photoinduced phytotoxicity of PAHs, the effects of intact and photomodified PAHs on the terrestrial plant *Brassica napus* (canola) during germination and early seedling growth were probed. Significantly, germination and early growth assays can be performed in the light or dark, making it possible to test for the absolute requirement of photoinduction with respect to the toxicity of intact and photomodified PAHs. Experiments were completed in simulated solar radiation (SSR; a light source with a visible light:UV-A:UV-B ratio equivalent to that of sunlight), visible light (vis) and darkness with intact and photomodified anthracene (ANT, pmANT), benzo[a]pyrene (BAP, pmBAP), and fluoranthene (FLA, pmFLA).

**MATERIALS AND METHODS**

The toxicity tests reported here were based on following the germination and early growth of *B. napus* L. cv Topas (canola) seeds. A general guide for this type of toxicity test can be found in the ASTM Standard Practice for Early Seedling Toxicity Tests (ASTM, 1994). In preparation for each test, *B. napus* seeds were washed 10 times with filter-purified (ultrafiltration) water (FP-H$_2$O) and placed on seed trays (Wang, 1993) in petri dishes with 30 ml of the test solution. All toxicity tests were performed with 12 seeds per dish and were replicated 9 times. Germination and early growth assays were conducted for 6 days. Light conditions and endpoints of chemical impact are described below. Concentrations for a 50% effect, EC$_{50}$, were derived from the dose–response curves. Statistical analyses (calculations of means and standard errors) were performed for all applicable experiments.

Germination tests on *B. napus* seeds were performed on polystyrene seed trays (Wang, 1993) in 100 × 15-mm polystyrene petri dishes. To form the test solutions, ANT, BAP, and FLA (Sigma Chemical Co., St. Louis, MO) were dissolved in DMSO to concentrations ranging from 0 to 10 g liter$^{-1}$ and delivered to FP-H$_2$O by 1000-fold dilution to final PAH concentrations ranging from 0 to 10 mg liter$^{-1}$. At 2 mg liter$^{-1}$, solutions of ANT, BAP, and FLA are 11.0, 8.0, and 9.7 μM, respectively. Due to their low solubilities in water, PAHs were delivered in DMSO to achieve concentrations that allow for full-scale dose–response curves (Neff, 1979). The final DMSO concentration in solution (0.1% v/v) does not interfere with availability of PAHs nor does it affect plant growth (Huang et al., 1993; Ren et al., 1994). Control seeds were always exposed to this concentration of DMSO. Accuracy of PAH delivery to water was determined spectroscopically as previously described (Huang et al., 1993). Once a toxicity test is started, photomodification and bioaccumulation of the PAHs begins; it then becomes impractical to further monitor the concentration of the PAH. To compensate, the test solution was replenished every 48 hr by static renewal.

During the seed germination tests irradiation was provided as either visible light (cool-white fluorescent) or SSR (Huang et al., 1993; Ren et al., 1994; Greenberg et al., 1995). Photon fluence rates are given in the figure legends. The spectral output of the SSR source following passage through a polystyrene petri dish cover (Fig. 1A) had a visible light:UV-A:UV-B ratio of 100:10:1, based on the number of photons. While this spectral output does not precisely replicate sunlight, the ratio of visible light:UV-A: UV-B is parallel to that of terrestrial sunlight from mid-spring to mid-fall in latitudes corresponding to southern Canada and the northern United States (Greenberg et al., 1995). The spectrum of the SSR source below the seed tray was also measured (Fig. 1B). Since the seed tray only slightly altered the spectrum, removing some of the UV-B, the seedling roots were subjected to irradiation with characteristics similar to that received by the shoots.

Toxicity was assessed on the basis of inhibition of accu-
mulation of root or shoot fresh weight relative to control seedlings. The germination frequency was also quantified on Days 1, 2, 3, and 6 of the test; it is defined as a visible cracking of the seed coat, even if there was not measurable root or shoot production. As well, the total number of roots over 1 mm in length were scored and their lengths were measured. Those seeds where the seed coat broke, but produced roots under 1 mm, were not included in statistical calculations of root length. To further quantify the level of toxicity in the shoots the extent of chlorosis was determined (Greenberg et al., 1991).

Toxicity of photomodified PAHs was assessed by root and shoot growth, and chlorosis as per the intact chemicals. Photomodified PAHs were generated by delivery of intact chemicals in DMSO to a final concentration of 8 mg liter\(^{-1}\) in FP-H\(_2\)O and incubated in sealed containers under UV-B radiation (25 \(\mu\)mol m\(^{-2}\) from 290 to 320 nm) for 5 days for ANT and 7 days for BAP and FLA. Half-lives of intact chemicals under these conditions are: ANT, 3 hr; BAP, 33 hr; and FLA, 20 hr. Photomodification was judged to be complete on the basis of absorbance criteria as previously described (Huang et al., 1993; Ren et al., 1994). Because more than 20 photoproducts are generated from each PAH, and most of these are unidentified at present, the concentrations of the photomodified PAHs were based on amount of the intact PAHs (Huang et al., 1993; Ren et al., 1994). It was previously demonstrated that toxicity of photomodified PAHs can be assessed based on the concentration of the parent compounds (Huang et al., 1993, 1995; Ren et al., 1994). The chemical concentration was adjusted by dilution with FP-H\(_2\)O and applied to the seeds.

**RESULTS**

To extend the work on the photoinduced toxicity of PAHs to the aquatic higher plant *L. gibba*, the effects of ANT, BAP, and FLA were tested on *B. napus* in the presence of SSR. The order of toxicity of the three PAHs, applied in the intact form, was ANT > BAP > FLA (Fig. 2). Under 250 \(\mu\)mol m\(^{-2}\) s\(^{-1}\) of SSR, ANT had a impact threshold of 0.5 mg liter\(^{-1}\) and an effective concentration for 50% diminishment (EC\(_{50}\)) of root fresh weight accumulation at 1 and 2 mg liter\(^{-1}\). Conversely, FLA did not affect root growth below 2 mg liter\(^{-1}\) and plateaued at 50% lower root fresh weight at 4 mg liter\(^{-1}\). The PAHs had a greater impact on root growth than on either shoot fresh weight accumulation or chlorophyll content, reflecting the hydroponic route of application and poor transport of PAHs from the roots through the plant vascular systems (Edwards, 1983).

Because roots in soil are not exposed to sunlight, intact PAHs will probably have a limited effect on them. However, it has been demonstrated that PAH toxicity to *L. gibba* increases following photomodification. PAH photomodifica-

![FIG. 2. Toxicity of intact ANT, BAP, and FLA to Brassica napus.](Image)

The PAHs were applied hydroponically to the plants at the concentrations indicated. The light source was SSR (250 \(\mu\)mol m\(^{-2}\) s\(^{-1}\)). Squares represent relative root growth (fresh weight accumulation) as a percentage of control growth. Triangles represent relative shoot growth (fresh weight accumulation) as a percentage of control growth. Circles represent relative chlorophyll (Chl) content as a percentage of chlorophyll in the control plants. Error bars are SEM (\(n = 9\)).
FIG. 3. Toxicity of pmANT, pmBAP, and pmFLA to *Brassica napus*. The photomodified chemicals were applied at the concentrations indicated. The concentrations are based on the amount of intact chemical prior to photomodification. The light source was SSR (250 \( \mu \text{mol m}^{-2} \text{s}^{-1} \)). Squares represent relative root growth (fresh weight accumulation) as a percentage of control growth. Triangles represent relative shoot growth (fresh weight accumulation) as a percentage of control growth. Circles represent relative chlorophyll (Chl) content as a percent of chlorophyll in the control plants. Error bars are SEM (\( n = 9 \)).

TABLE 1

<table>
<thead>
<tr>
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<th>1</th>
<th>2</th>
<th>3</th>
<th>6</th>
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<tr>
<td><strong>Control</strong></td>
<td>73 (3.6)</td>
<td>88 (2.7)</td>
<td>94 (1.5)</td>
<td>96 (1.1)</td>
</tr>
<tr>
<td><strong>ANT</strong></td>
<td>70 (4.7)</td>
<td>85 (3.0)</td>
<td>94 (2.2)</td>
<td>96 (1.9)</td>
</tr>
<tr>
<td><strong>BAP</strong></td>
<td>77 (3.7)</td>
<td>96 (2.2)</td>
<td>98 (1.1)</td>
<td>98 (1.1)</td>
</tr>
<tr>
<td><strong>FLA</strong></td>
<td>68 (4.6)</td>
<td>87 (3.6)</td>
<td>94 (1.8)</td>
<td>98 (1.7)</td>
</tr>
</tbody>
</table>

Note. The percent of seeds that germinated in the presence of no PAHs (control), ANT (10 mg liter\(^{-1}\)), BAP (10 mg liter\(^{-1}\)), or FLA (10 mg liter\(^{-1}\)) at various times during a toxicity experiment.

\(^*\) Days after application of chemical.

\(^*\) Percentage germination (SEM in parentheses, \( n = 9 \)).

Accordingly, the chemicals must be inhibiting root growth by altering the ability of the roots to accumulate fresh weight.

The number of roots produced and/or the size of the individual roots could be affected by the PAHs. First, the total number of roots produced in 6 days was quantified. For the intact PAHs there was no effect on the total number of roots produced; approximately 90% of control and treated seeds produced a measurable root in 6 days (defined here as 1 mm or more in length, Fig. 4). However, photomodified ANT caused a moderate decrease in the number of roots produced; about 60% of the seeds produced a measurable root (Fig. 4). Photomodified BAP only slightly diminished the number of measurable roots produced, while pmFLA had no effect on the number of roots produced. Therefore, in general, the effects of PAHs on *B. napus* cannot be attributed to diminished root production.

Another possible effect of the chemicals is on root elongation. Control seedlings in SSR had an average root length of 18.2 mm (Table 2) and exhibited a distribution of roots over a 1–60 mm range, with the number of roots in each successive 10-mm interval exhibiting a gradual decline (Fig. 5). Conversely, for intact ANT and BAP, the distribution in root lengths is skewed toward shorter lengths, with mean root lengths of 8.9 and 12.5 mm, respectively (Fig. 5A). In particular, in the presence of ANT the vast majority of roots are shorter than 10 mm. On the other hand, plants grown in the presence of FLA had an average root length (22.1 mm) and a distribution of root lengths very similar to the control.
TABLE 2

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>ANT</th>
<th>BAP</th>
<th>FLA</th>
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<tbody>
<tr>
<td><strong>Intact</strong></td>
<td>18.2 (0.8)</td>
<td>8.9 (0.9)</td>
<td>12.5 (0.7)</td>
<td>22.1 (1.3)</td>
</tr>
<tr>
<td><strong>Photomodified</strong></td>
<td>18.2 (0.8)</td>
<td>5.0 (0.4)</td>
<td>14.6 (1.1)</td>
<td>19.7 (1.2)</td>
</tr>
</tbody>
</table>

Note. All experiments were performed in SSR (250 μmol m⁻² s⁻¹). Chemical concentrations were based on intact chemicals. ANT, BAP, FLA, pmBAP, and pmFLA were applied at 4 mg liter⁻¹ and pmANT was applied at 1 mg liter⁻¹.

Average root length in mm (SEM in parentheses, n = 9). Calculations included only those seeds which produced a root 1 mm or longer.

With the finding that PAHs affect root fresh weight accumulation and elongation in SSR, we determined if PAHs also have negative impacts on the seedling roots in the absence of UV radiation or in darkness. *B. napus* seeds were germinated in SSR (100 μmol m⁻²), visible light (100 μmol m⁻²), and darkness for 6 days in the presence of intact PAHs. None of the intact PAHs had an effect on root fresh weight in darkness (Fig. 6). Inhibition of root fresh weight accumulation for BAP and FLA was similar in SSR and visible light (Fig. 6). However, for ANT root fresh weight accumulation was markedly depressed in SSR but there was no effect in visible light. Thus, for all three chemicals in intact form there was a requirement for light, but only in the case of ANT was there an absolute requirement for UV radiation.

To determine if photomodified PAHs require visible light or UV radiation to be hazardous, seeds were germinated in SSR (100 μmol m⁻²), visible light (100 μmol m⁻²), and darkness for 6 days. Photomodified ANT exhibited similar effects on root fresh weight accumulation under all three lighting conditions (Fig. 6), indicating the toxicity of pmANT is not dependent on actinic radiation. Photomodified BAP diminished root fresh weight accumulation by the same amount in the dark and visible light (75% of control); however, growth was much slower in SSR (only 40% of control). This indicates that the toxicity of pmBAP was enhanced by UV radiation. Nonetheless, photomodified PAHs derived from both ANT and BAP have an impact on the plants without further photoactivation. In contrast, pmFLA did not

seedlings. Nonetheless, FLA does cause lower fresh weight accumulation in roots, implying that these plants have thin roots or roots that are not retaining water as well as the control seedlings.

The effect of the photomodified PAHs on the length of roots was similar to the intact PAHs, but more pronounced for pmANT (Fig. 5B). The longest root lengths for pmANT were in the 11 to 20-mm range and the mean root length was only 5.0 mm. Interestingly, there was no discernible difference in the effects between intact BAP and pmBAP or between intact FLA and pmFLA, with each pair of chemicals affecting the distribution of root lengths to the same degree (Fig. 5). As well, the mean root length for each pair was virtually identical (Table 2).

FIG. 5. Length distribution of *Brassica napus* roots. *B. napus* seeds were germinated in the presence of ANT, BAP, FLA, pmANT, pmBAP, or pmFLA in SSR (250 μmol m⁻² s⁻¹). All chemical concentrations were 4 mg liter⁻¹ except pmANT which was 1 mg liter⁻¹. Each histogram represents the average number of roots per petri dish in successive 10-mm length intervals for the control and chemically treated seeds. (A) Intact PAHs; (B) photomodified PAHs.
inhibit root growth in the dark (Fig. 6), but did inhibit root fresh weight accumulation in SSR and visible light. Furthermore, inhibition by pmFLA in SSR was greater than in visible light, indicating that the toxicity of pmFLA is enhanced by UV radiation, as was the case for pmBAP.

**DISCUSSION**

ANT, BAP, and FLA in their intact and photomodified forms are toxic to the terrestrial plant *B. napus*. Similar to the toxicity of PAHs to the aquatic plant *L. gibba* (Huang *et al.*, 1993; Ren *et al.*, 1994), the toxicity of the intact PAHs to *B. napus* was photoinduced. Additionally, the toxic activity of the chemicals was enhanced following photomodification of the parent compounds. Interestingly, actinic radiation is not absolutely required to induce the toxicity of pmANT or pmBAP. The toxic effect of both intact and photomodified PAHs was manifested as inhibition of root fresh weight accumulation. This was attributed to shorter roots in the presence of intact or photomodified ANT and BAP. However, intact and photomodified FLA inhibited root fresh weight accumulation without affecting root lengths.

The toxicity of PAHs to *B. napus* was dependent on the concentration of the intact PAH in solution, exhibiting an approximately log-linear response to concentration. The EC$_{50}$ range of 1–4 mg liter$^{-1}$ for intact ANT, BAP, and FLA is consistent with the levels of PAHs required to inhibit *L. gibba* growth by 50% (Huang *et al.*, 1993; Ren *et al.*, 1994). This is also consistent with the levels of PAHs found in contaminated soils and sediments (Suess, 1976; Cook *et al.*, 1983; Nikolaou *et al.*, 1984; Jones *et al.*, 1989; Ankley *et al.*, 1994).

Photomodified PAHs exerted toxic effects similar to the intact compounds but at lower concentrations. This is also consistent with the work done with *L. gibba* (Huang *et al.*, 1993; Ren *et al.*, 1994), where the photomodified PAHs had an EC$_{50}$ range of one-half that of the intact PAHs. ANT, whether intact or photomodified, was invariably the most toxic of the three PAHs tested, which is also consistent with the work with *L. gibba* (Huang *et al.*, 1993; Ren *et al.*, 1994). The levels of photomodified PAHs that caused subacute toxicity are within the range of environmental loadings of intact PAHs (0.05–0.5 mg liter$^{-1}$) in many industrialized regions (Basu and Saxena, 1978; Neff, 1979; Cook *et al.*, 1983; Eadie, 1984).

The toxic effects of the PAHs to *B. napus* was first evident in the root systems of the plants. Only at high concentrations was an effect in shoot development and chlorophyll content observed. This is consistent with the uptake of the toxicants by the roots of the germinating seedlings during hydroponic application of the PAHs to the roots. Because PAHs are hydrophobic and known to partition into lipid membranes (Neff, 1979; Edward, 1983), it is expected that they will accumulate in the membranes of the root system where the chemicals first contact the plants. Only at extremely high concentrations (4–10 mg liter$^{-1}$), when the roots are saturated with the chemicals, can movement of the PAHs through the plant to the shoots be assumed (Edwards, 1983). Additionally, at high PAHs concentrations the ability of the roots to assimilate water and nutrients would be compromised, which would impact on shoot growth and photosynthesis.

Germination of the seeds was unaffected by the PAHs whether applied in intact or photomodified form. Thus, the decline in root fresh weight accumulation was not attributable to a delay in germination or to a decrease in the germination frequency. The effects can be traced chiefly to inhibited root growth (fresh weight accumulation). In the presence of ANT, BAP, pmANT, or pmBAP, dramatically shorter roots were produced by the seedlings. Furthermore, pmANT caused the germinated seeds to produce fewer roots relative to the control seedlings. At the early stages of plant development examined here, root growth is due primarily to cell expansion and not cell division (Taiz and Zeiger, 1991). Therefore, cell expansion is probably being impeded, which could occur, for example, by inhibition of hormone action (e.g., auxin) or interference with cellular metabolism (e.g., mitochondrial function). Interestingly, it was recently demonstrated that photomodified PAHs inhibit cytochrome c oxi-
dase (Huang, 1995), the terminal oxidase in mitochondrial electron transport.

On the other hand, FLA seemed to inhibit root fresh weight accumulation by a different mechanism. Both FLA and pmFLA had no effect on the length of the roots or number of roots; however, root fresh weight accumulation was clearly inhibited relative to the control. This phenomenon could be attributable, for example, to FLA causing a mechanical disruption to the membranes which would weaken the fragile cellular structure of the new roots (Taiz and Zeiger, 1991). This could diminish the capability of the cells to retain water, leading to a decline in root fresh weight accumulation without necessarily disturbing the elongation process.

In previous work with L. gibba the role of fluence rate and spectral quality on the photoinduced toxicity of PAHs was investigated (Huang et al., 1993; Ren et al., 1994). Given that vegetative growth of L. gibba is light dependent, these experiments could not be performed in the dark to determine if there is an absolute requirement for actinic radiation to activate the toxicity of PAHs. However, terrestrial plants can be germinated in the absence of light. During the 6-day dark germination experiments in 10 mg liter\(^{-1}\) of a given PAH (highly toxic levels for each in SSR) no inhibitory affect on root growth was observed (Fig. 6). This was in marked contrast to the inhibition seen in the presence of SSR and visible light. In SSR, ANT (10 mg liter\(^{-1}\)) inhibited root fresh weight accumulation by 75%, while in the presence of visible light it did not inhibit growth. This is consistent with ANT’s strong absorption in the UV region and lack of absorption in the visible region of the spectrum (Huang et al., 1993). Clearly, UV induced sensitization and/or photomodification reactions are necessary for intact ANT to induce toxicity in plants. Both BAP and FLA (10 mg liter\(^{-1}\)) inhibited root fresh weight accumulation by 50% in SSR and visible light. BAP absorbs both in the UV and in the visible regions of the spectrum (Huang et al., 1993), and so photosensitization and photomodification reactions can occur in both of these spectral regions. The case with FLA is not as clear. In organic solvents, FLA does not absorb strongly in the visible spectral region (Ren et al., 1994), yet the degree of root fresh weight inhibition was the same in SSR and visible light. It is possible that FLA exerts toxicity through a different mechanism than ANT and BAP, which would be consistent with its different symptoms of stress vis-à-vis root elongation. Additionally, the absorbance spectrum of FLA might be shifted to longer wavelengths within biological membranes or while bound to cellular macromolecules making it subject to UV excitation.

For the photomodified PAHs, dark germination of B. napus in a chemical concentration of 4 mg liter\(^{-1}\) (highly toxic levels for each in SSR) resulted in inhibition of root fresh weight accumulation in the presence of pmANT and pmBAP (Fig. 6). On the other hand, pmFLA has an absolute dependence on light to exert toxicity. This is consistent with the work done with L. gibba (Ren et al., 1994), where the toxicity of FLA and pmFLA were both found to be strongly enhanced by actinic radiation. Photomodified BAP moderately inhibited root growth (25%) in the dark and visible light, while in SSR, UV activation increased inhibition of growth to about 60%. Thus, only part of the toxic potential of pmBAP is realized in the absence of UV radiation. Interestingly, pmANT is the strongest inhibitor of root growth with a level of inhibition (75%) independent of lighting conditions. Thus, the photomodification products of ANT are toxic without further photochemistry.

**CONCLUSION**

The toxicity of PAHs to a terrestrial plant species (B. napus) is strongly enhanced by actinic radiation when the compounds are applied in intact form. Once PAHs are photomodified, however, they become more toxic than the parent compounds. Strikingly, photomodified PAHs are not absolutely dependent on actinic radiation for inhibition of root growth. Because PAHs frequently enter the environment via atmospheric and aquatic disposition, the probability of photomodification in the environment is quite high. The photomodified PAHs can then migrate to environmental compartments that are not exposed to sunlight and exert toxic effects. Furthermore, the photomodified products of PAHs are more water soluble than the parent compounds and therefore are more readily dispersed throughout the biosphere. In the past intact PAHs were considered to be eliminated by exposure to sunlight. This exposure, however, photomodifies the chemicals to numerous products that are themselves potential environmental hazards. Thus, not only is it imperative to identify the photomodification products from PAHs, it is crucial to determine their toxicity and half-lives in the environment.

**ACKNOWLEDGMENTS**

The authors are grateful to Xiao-Dong Huang, Cheryl Duxbury, Bob Gensemer, Mike Wilson, Brendan McConkey, and other members of the Greenberg and Dixon labs for fruitful discussions. This research was supported by a grant from the Canadian Networks of Toxicology Centres and NSERC Strategic and Research Grants to B.M.G. and D.G.D.

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