A literature search revealed that the ^{1}H-NMR data of **3** correspond to those reported[9] for synthetic 9-[5′-deoxy-5′-(methylthio)-β-D-xylofuranosyl] adenine. A direct comparison of the ^{1}H-NMR spectra of natural and synthetic **3**[10] confirmed the identification.

From a biogenetic point of view compound **3** could reasonably be derived by cleavage of the analog of AdoMet carrying a deoxyxylofuranosyl moiety (**4**), in a fashion which is similar to the origin of MTA from AdoMet. The interest in the analogs and derivatives of AdoMet lies mainly in the possibility of modification and control of the transmethylation reactions. Since it is the first time that a MTA analog has been detected in nature, the conjecture just cited suggests that analogs of AdoMet might also occur in living systems.

To our knowledge, compound **3** also constitutes the first naturally-occurring purine carrying a xylose derivative substituent.

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Naturally-occurring crystals of photocarcinogenic furocoumarins on the surface of parsnip roots sold as food

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Summary. Normal levels of total furocoumarins in fresh parsnip roots are as high as 96 ppm (wet weight). In older 'spoiled' and diseased parsnips freely available in grocery stores these values may be increased by 2500%. So high are the amounts in some instances, that mixed crystals of furocoumarins can be detected on the surfaces of the parsnip roots by both conventional low powered microscopy and SEM. The principal crystal form was angelicin but the presence of psoralen, 5-MOP and 8-MOP was confirmed by HPLC, TLC, photobiological assay and analysis of mass spectra.
Key words. Parsnip; furocoumarins; photocarcinogenesis; 5-methoxypsoralen; 8-methoxypsoralen; psoralen; angelicin; photosensitivity.

A number of plants belonging to the family Umbelliferae produce linear and angular furocoumarins (fig. 1) of which psoralen may be taken as representative of the former and angelicin of the latter. Increased levels of these molecules are probably associated with the phytoalexin response to stress[1,2] even though levels of furocoumarins may be normally high in many Rutaceae and Umbelliferae. Linear furocoumarins such as psoralen and 5-methoxypsoralen (5-MOP) can, in the presence of near ultraviolet (UV), produce both DNA monoadducts and the more lethal DNA-DNA interstrand crosslinks. Angular furocoumarins such as angelicin, under normal circumstances, form DNA monoadducts only[3]. When excited by near UV radiation (300–380 mn) furocoumarins produce lethal, mutagenic and clastogenic effects in numerous animal and human cells[4,5]. Skin cancer in animals[6,7] and probably in man[8,9] are known consequences of photosensitization with furocoumarins.

Skin photosensitivity after contact with diseased celery, a plant belonging to the Umbelliferae, has been established[10] to result from the large amounts of three furocoumarins: psoralen, 5-methoxypsoralen (5-MOP) and 8-methoxypsoralen (8-MOP). Ivie et al.[11], have drawn attention to the presence of furocoumarins as natural toxicants in parsnips. Total concentrations as high as 40 ppm were reported and the relevance of these findings to human consumption has been discussed by Ames[12]. Numerous reports on the adverse effects of contact with parsnips have appeared in the literature including several in which troops had been suspected of contact with mustard gas, so severe were the skin reactions[13].

Methods. The HPLC techniques for the analysis of furocoumarins in plants together with the ultrasensitive biological assays following two dimensional TLC have been described previously[14–16]. Parsnips were obtained in Victoria, British Columbia, Canada.

Results and discussion. During the course of previous studies on celery[4,14] we were surprised to find, on occasions, very high levels of furocoumarins in some parsnip samples. These were levels far in excess of those reported by Ivie et al.[11] and greater even than the levels of 8-MOP in parsnip pieces infected with fungus and grown in vitro[17]. Examination of several 'spoiled' parsnip roots with a low power dissection microscope revealed the presence of what appeared to be small pieces of fungal mycelium but which,

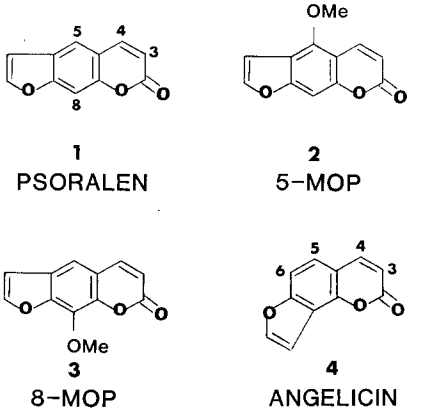


Figure 1. Formulae of photosensitizing furocoumarins found in parsnip root.

Concentrations of photoactive furocoumarins in normal and diseased parsnips. (Values in μg/g wet wt ± SEM)

Parsnip	Angelicin	5-MOP	Psoralen	8-MOP	Total furocoumarins
Root, whole	34.1 ± 2.0	7.3 ± 0.7	7.1 ± 1.4	48.0 ± 6.5	96.5 ± 9.0
Root, peel	113.8 ± 19.8	22.5 ± 4.4	9.4 ± 2.9	154.4 ± 30.9	300.1 ± 56.0
Root, diseased area	723.0 ± 139.0	90.8 ± 15.8	537.0 ± 220	1109.0 ± 185.0	2459.8 ± 515.0

Comparisons for values of individual and total furocoumarin concentrations between whole root and diseased roots were all significant ($p = 0.01$ or greater; Mann-Whitney Test).

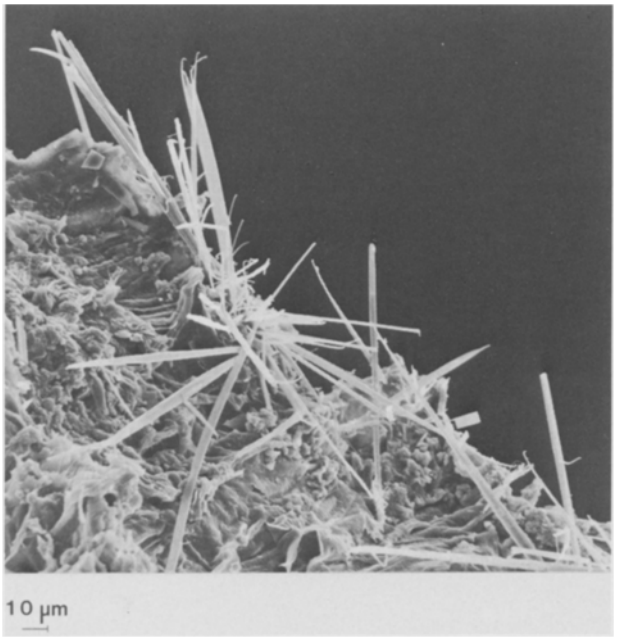
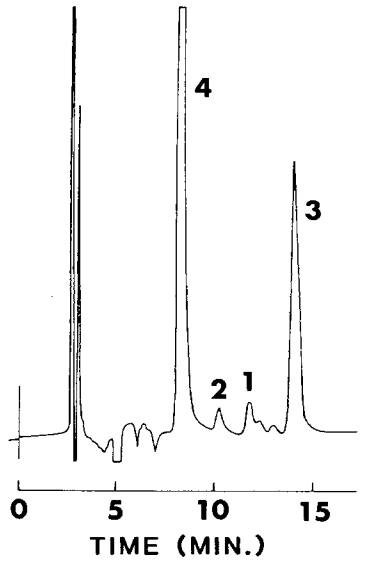


Figure 2. Scanning electron photomicrograph of furocoumarin crystals on the surface of 'spoiled' parsnip root. Long needle crystals are angelicin.

on closer examination, were clearly revealed as crystals by high power microscopy and SEM (fig. 2). Careful removal of the crystals and analysis by HPLC and photobiological assay following TLC indicated that the major crystal component was angelicin, confirmed by HPLC, determination of mass spectra and melting point. 5-MOP, 8-MOP and psoralen were also present in the crystal mass. The results of HPLC and photobiological assay are shown in figure 3. The differences in growth inhibition (seen as clear zones in the bacterial carpet) relative to the HPLC peaks are related to the differential sensitivity of the photoassay for furocoumarins[16]. Angelicin, for example, is between five and ten times less active on a molar basis than the linear furocoumarins.

When various parts of parsnip roots were analyzed by HPLC (see table) the reason for crystal formation on the surface became apparent. Values as high as 2459 ppm (2.4 mg/g wet wt) for total furocoumarins were observed with individual values of 723 ppm, 90 ppm, 537 ppm and 1109 ppm for angelicin, 5-MOP, psoralen and 8-MOP respectively. The exact composition of the crystal mass varies from sample to sample. Normal values for 'healthy' parsnip roots were 96 ppm for total furocoumarins with individual values of 34 ppm, 7 ppm, 7 ppm and 48 ppm respectively for angelicin, 5-MOP, psoralen and 8-MOP. All samples, both healthy and diseased, contained varying amounts of the non-photoactive molecule isopimpenillin, as well as trace quantities of imperatorin.

Our results demonstrate clearly that parsnips sold as food contain, under normal circumstances, higher levels of photocarcinogenic furocoumarins than previously reported[11]. With 'spoiled' or diseased parsnips available in stores and supermarkets, the values were so high as to result in the formation of mixed surface crystals easily deposited on hands and worksurfaces. A recent comment in the Journal of the American



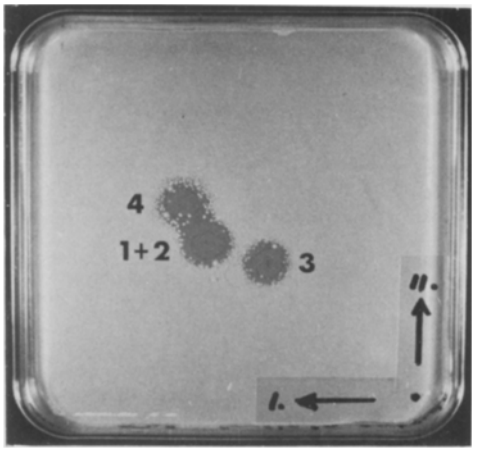


Figure 3. Furocoumarin composition of surface crystals from 'spoiled' parsnip root. Top: HPLC tracing of crystals (≡1.5 μg) removed from the root surface and dissolved in chloroform. Samples were analyzed on a Varian Si 5 column (30 cm × 4 mm) using cyclohexane: iso-propylether: n-amyl alcohol (15:4:0.5) with a flow rate of 1 ml/min. Detection at 254 nm. 1 = psoralen, 2 = 5-MOP, 3 = 8-MOP, 4 = angelicin. (Details and methodology, Ashwood-Smith et al., J. chem. Ecol. *12* (1986) 915). Retention times were used for standardization. Quantitation was done by peak area integration with an HP 3390. Bottom: Photobiological assay. Chromatographic pattern of crystal sample (≡1×10^{-9} g) after 2D TLC analysis on Merck 60 silica sheets (absence of fluorescent indicator). Solvent I = chloroform. Solvent II = hexane: pentane: ethyl acetate (35:35:30). The chromatogram was viewed with near UV (300–380 nm) and then assayed photobiologically[16]. The dark areas represent inhibition zones of bacterial growth due to the presence of photoactive furocoumarins (labeling as in top diagram). Separation of psoralen (1) and 5-MOP (2) was incomplete. Angelicin, although the major component, is less active photobiologically than 5-MOP, 8-MOP or psoralen in this assay and thus the inhibition zone surrounding angelicin is smaller than its concentration would indicate.

Medical Association[18] suggested that photosensitizing problems with supermarket clerks and food handlers were probably associated with celery handling and the 'presence of psoralen-containing agents'. Ivie[11] has stated that the peeling of parsnips would reduce the problem but we have found amounts of total furocoumarins as high as 100 ppm underneath the diseased surfaces and in tissue which is apparently normal. Cooking does not destroy furocoumarins[11].

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The World Health Organization has included 8-MOP and PUVA (psoralen-ultraviolet A) phototherapy for psoriasis in a list of carcinogens causally related to human cancer[9]. Angelicin, as a monofunctional DNA photoalkylating agent is considered less carcinogenic than the linear furocoumarins[19,20]. However, the large amounts of this chemical together with the high levels of 5-MOP, 8-MOP and psoralen in such a highly prized vegetable is cause for some debate and discussion.

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