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TB107: Effects of Some Naturally Occurring Chemicals and Extracts of Non-Host Plants on Feeding by Spruce Budworm Larvae (Choristoneura fumiferana)

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EFFECTS OF SOME NATURALLY OCCURRING CHEMICALS AND EXTRACTS OF NON-HOST PLANTS ON FEEDING BY SPRUCE BUDWORM LARVAE, (*CHORISTONEURA FUMIFERANA*)

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LIFE SCIENCES AND AGRICULTURE EXPERIMENT STATION
UNIVERSITY OF MAINE AT ORONO

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EFFECTS OF SOME NATURALLY OCCURRING CHEMICALS AND EXTRACTS OF NON-HOST PLANTS ON FEEDING BY SPRUCE BUDWORM LARVAE, CHORISTONEURA FUMIFERANA

M.D. Bentley, D.E. Leonard, S. Leach, E. Reynolds, W. Stoddard, B. Tomkinson, D. Tomkinson[1], G. Strunz[2], M. Yatagai[3]

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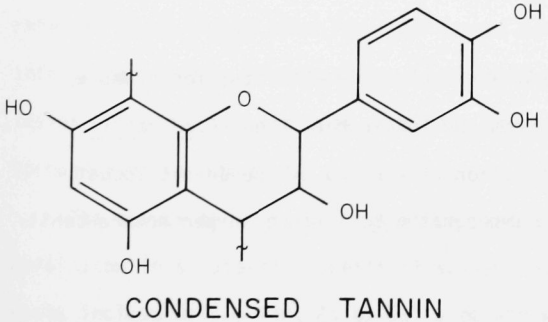
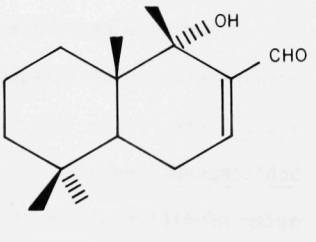
INTRODUCTION

Until recent times the role of so-called secondary substances[1] in plants remained unappreciated and it was generally felt that these compounds were simply stored by-products of primary metabolism. In the past two decades, it has become increasingly evident that this structurally diverse group of phytochemicals exerts an often subtle, but exceedingly important, effect on host plant selection by phytophagous insects. Indeed, for certain insects, some investigators feel that secondary substances may play a leading role in determining patterns of utilization[2] and that this aspect of the current theory of insect-plant interactions may in part explain the enormous diversity exhibited in the plant and insect kingdoms and in the chemistry of secondary compounds in plants[3,4].

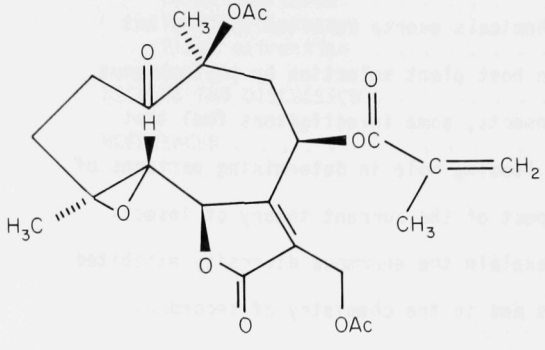
A substantial number of plant allelochemicals which function as insect feeding deterrents have now been reported[4-9] These compounds exhibit great structural variety - phenylpropanes, acetogenins, terpenoids, steroids, and alkaloids are all represented in this group. Some examples of known naturally occurring feeding deterrents which illustrate this structural diversity are shown below by condensed tannin (I), warburganal (II), glaucolide A (III), and demissine (IV).



CONDENSED TANNIN
I

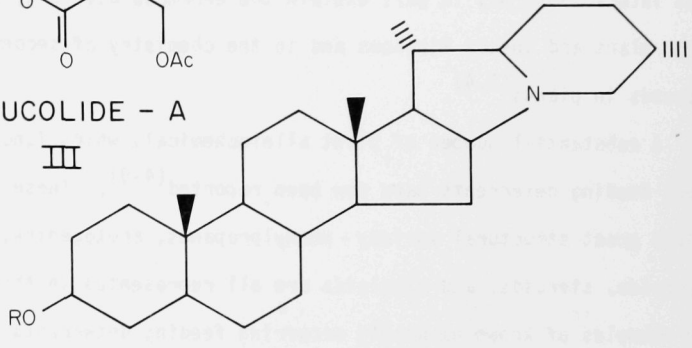


WARBURGANAL
II



GLAUCOLIDE - A

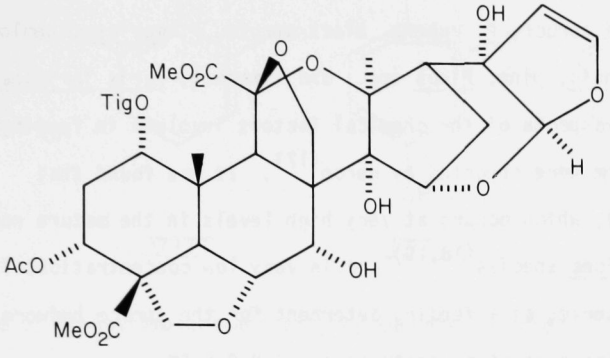
III



DEMISSINE (R - β - LYCOTETRAOSE)

IV

Some deterrents exhibit extremely high activity; for example, azadirachtin (V), isolated from the Indian neem tree, Azadirachta indica, results in 100% inhibition of feeding by the desert locust, Schistocerca gregaria, when impregnated at 1 nanogram per square centimeter of filter paper[11]



AZADIRACHTIN

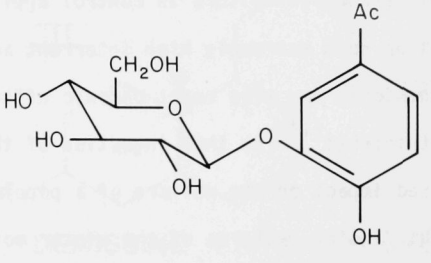
V

The potential efficacy of feeding inhibitors in control applications is not necessarily dependent on such extremely high deterrent activity. It is known that allelochemicals may also exert chronic effects on growth and development of insects[14] so that ingestion of these substances may have a deferred impact on the welfare of a population. In a now classic study of the feeding patterns of the winter moth, Feeny[10] found that this insect, a prime defoliator of the oak, Quercus robur, experiences a significant reduction in larval growth rate and pupal weight when fed upon leaves collected after the normal infestation period. At this time, condensed tannin concentration in leaves is high; thus there is a paucity of available protein due to the formation of tannin-protein complexes.

The spruce budworm, Choristoneura fumiferana, is the principal defoliator in spruce-fir forests of eastern North America. Preferred hosts include balsam fir. Abies balsamea and white spruce, Picea glauca,

but the larvae of this tortricid also feed on other species of conifers including red spruce, P. rubens, black spruce, P. mariana, hemlock, Tsuga canadensis, pine, Pinus spp., and tamarack, Larix laricina[15,16].

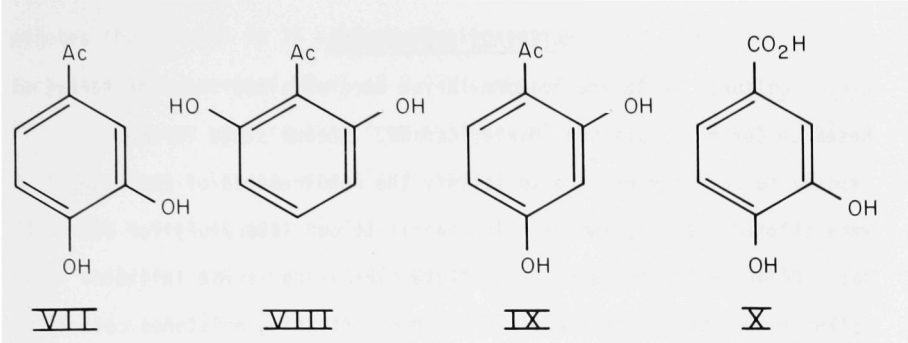
Certain aspects of the chemical factors involved in feeding by spruce budworm were reported by Heron[17] It was found that pungenin (VI), which occurs at very high levels in the mature needles of various Picea species[18,19] and in very low concentrations in the new shoots, serves as a feeding deterrent for the spruce budworm in laboratory bioassays at concentrations of 0.2-5.0%.



PUNGENIN

VI

The aglucone (VII) was also found to be active, although somewhat less than (VI) and additionally, the related synthetic compounds (VIII-X) also deterred feeding activity.



Evidence of phagostimulant activity by sucrose and proline was also reported and the phytochemicals shikimic acid and caffeic acid stimulated feeding when present with sucrose.

Recently, Albert and Jerrett[20] have reported the results of single-choice and three-choice tests to determine the relative importance of host-plant chemical extracts in eliciting feeding by spruce budworm larvae. Water-soluble components of balsam fir were the most important, with the sugar and glycoside fractions of this extract displaying greatest stimulatory activity. The amino acid and organic base fractions had no apparent effect while the organic acid fraction deterred feeding slightly.

The response of insects to phytochemicals present in non-host plants is of considerable interest since the lack of insect adaptation to these substances increases the likelihood of finding biodynamic compounds exhibiting high activity as feeding deterrents, growth regulators, or insecticides. Herein we describe a new laboratory feeding bioassay and its application to the investigation of the effect of a large number of plant extracts and various natural products on feeding by sixth stage spruce budworms.

MATERIALS AND METHODS

Larval cultures -- Spruce budworm larvae were obtained from the Forest Research Centre, Sault Ste. Marie, Canada. Second stage larvae, exposed to cold temperature to satisfy the requirements of diapause, were shipped via air, and were in transit to our laboratory for one day. On arrival, strips of cheesecloth containing larvae in their silken hibernacula were placed in beakers containing moistened cotton and covered with Parafilm®. Larvae, on emerging, were collected from the sides and top of the beaker Larvae were transferred with a camel's hair brush to one ounce, clear plastic cups (8 larvae per cup) containing artificial diet of Leonard and Doane[21] and were then placed in a controlled temperature room maintained at 25^{+} 0.5^{o}C and 16 h photoperiod per 24 h day. Larvae were transferred at fourth stage to new cups containing fresh diet, with 3-4 larvae per cup.

Feeding bioassays -- The feeding bioassay was based on a comparison of feeding on 1.2 cm round paper penicillin assay discs. Heron[17] showed that larvae of the spruce budworm could be induced to feed on Japanese elder pith discs with an aqueous solution of various amino acids and sugars as a phagostimulant. Heron's best results were with 0.02M L-proline and 0.1M sucrose. We found we could enhance the amount of feeding by increasing the L-proline to 0.03M, and the sucrose to 0.3M.

Penicillin discs were prepared by placing them on a clean enameled tray, then treating with 50 µl of test material in 95% ethanol; control discs with 50 µl of 95% ethanol. Discs were allowed to dry for several

minutes then placed in 35 x 10 mm plastic petri dishes, one per dish. Each disc then received 50 µl of 0.03M L-proline and 0.3M sucrose.

Test larvae were removed from cultures 24 to 48 h after their molt to sixth stage. Larvae were placed individually into a 35 x 10 mm petri dish with a test or control disc. Each trial consisted of 20 insects, 10 of each sex, and a corresponding control. Two or more replicates of tests and controls were run for each compound tested. Petri dishes were capped and placed in a controlled temperature room at $25 \pm 0.5^{o}C$ and 16 h photoperiod. Twenty-four hours after the initiation of the test, both the control and test discs received an additional 50 µl of 0.3M L-proline and 0.3M sucrose. At 48 h after initiation of the test, the larvae were removed from the petri dishes. Using a dissecting microscope, the number of frass pellets was counted. The yellowish-brown frass pellets derived from the artificial food were easily differentiated from the white pellets derived from the paper discs. Frass pellets derived from the artificial food were not included in counts.

Tests in which mortality of the test insects or controls exceeded two larvae per replicate were discarded, and the tests were re-run. Although differential feeding rates have been shown between male and female larvae of spruce budworm (Koller and Leonard[22]), much of the differential occurs during the last half of the last larval stage. We found no consistent difference in frass produced by male and female larvae in the early part of the sixth stage when we conducted the bioassay, and the data on frass produced by both sexes were pooled in our analyses.

The number of frass pellets in the test and control insects were

compared for statistically significant differences using Student's paired t-tests, with the significance level at P = 0.05.

The percent deterrence was calculated as follows:

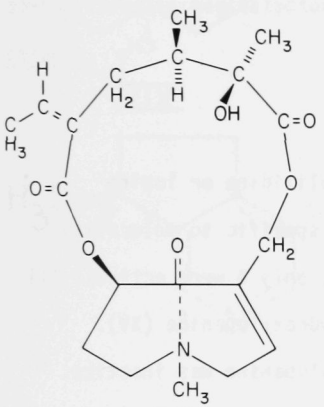
$$\left[1 - \frac{\text{number of pellets of frass in tests}}{\text{number of pellets of frass in controls}}\right] \times 100$$

Plant Extraction Freshly collected plant materials were finely chopped in a blender and extracted several hours at room temperature with 95% ethanol (10g plant material per 100 ml of ethanol). After removing insoluble plant residues by vacuum filtration, the ethanol extracts were stored at 0^{0} until used for bioassay.

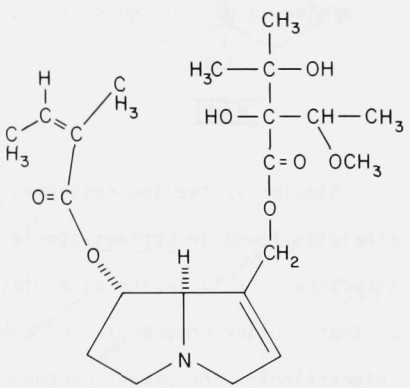
RESULTS AND DISCUSSION

In Table I are listed 109 plants which have been extracted and assayed during the course of this study. The feeding response to each in the spruce budworm feeding bioassay is broadly classified in activity groups with HD (75%-100% deterrency) representing highest activity. Although none of these plants is a normal host of spruce budworm larvae, only 6 extracts displayed high feeding deterrency. All plants in the most active group are known to contain alkaloids. Tomato, potato, and nightshade foliage contain various solanum alkaloids; lupine contains a mixture of quinolizidine alkaloids; coltsfoot contains senkirkine, a pyrrolizidine alkaloid; valerian contains pyridine alkaloids. In each case we have demonstrated that the greatest activity in these plant extracts is localized in the alkaloid-containing fractions. A number of alkaloids in the solanum, pyrrolizidine, and quinolizidine classes are

listed in Table II. A very interesting pattern which emerges from these studies is that although we see the greatest deterrency in plant extracts known to contain alkaloids, only a small percentage of alkaloids which we have assayed display significant activity. For example, of 14 pyrrolizidine alkaloids examined, only 2, senkirkine (XI) and lasiocarpine (XII) are highly deterrent.

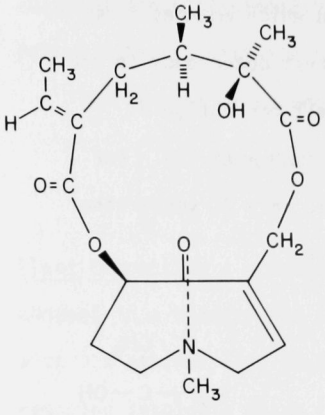


XI

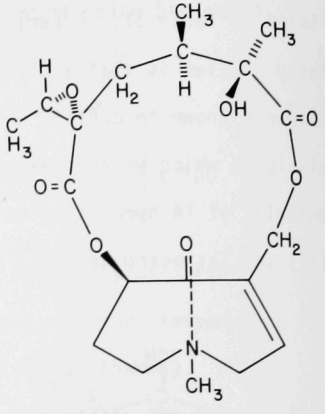


XII

Some relatively small structural changes in an active alkaloid can significantly alter its activity. When the stereochemistry about the 15, 16 double bond in (XI) is altered as in neosenkirkine (XIII) or when the 15, 16 double bond is epoxidized as in otosenine (XIV), activity drops dramatically.

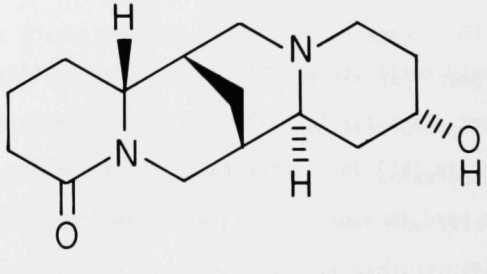


XIII



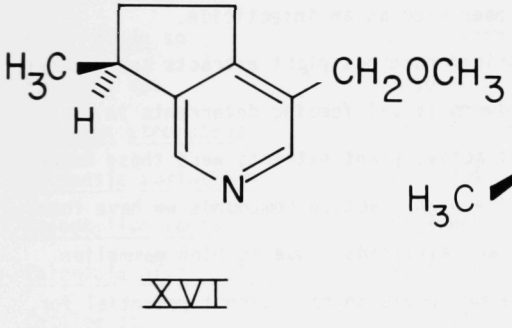
XIV

Similarly, feeding responses to the quinolizidine or lupine alkaloids found in Lupinus species are highly specific to molecular structure. Of 13 lupine alkaloids we assayed, only 3 were active. All of these active compounds were esters of 13-hydroxylupanine (XV). Interestingly, the parent compound, 13-hydroxylupanine was inactive.

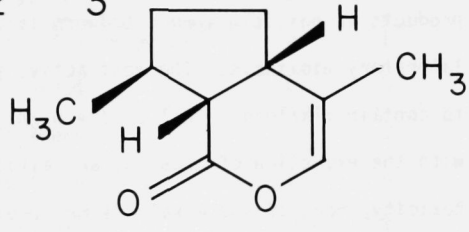


XV

Of 5 solanum alkaloids tested, 2 were highly deterrent (> 75% deterrency) and the remaining 3 were deterrent (>50% deterrency). We have not isolated the active components in the Valeriana officinalis at this time, but have established that activity is confined to the chloroform-soluble alkaloid fractions. Alkaloids known to be present in the genus Valeriana are in a class represented by the example valerianine (XVI). Interestingly, these alkaloids bear many structural similarities to nepetalactone (XVII) which is found in catnip, Nepeta cateria.



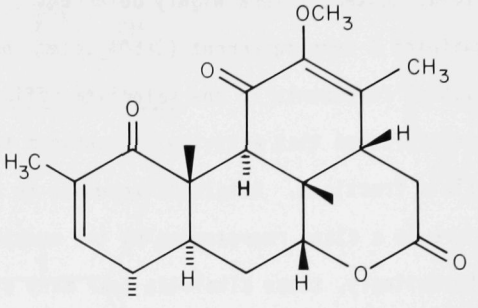
XVI



XVII

Extracts of the latter showed activity in the 50-75% deterrency range in our assays.

Of the non-alkaloidal natural products assayed, quassin (XVIII) displayed the highest deterrency (close to 70%).



XVIII

Quassin is found in the wood of the tropical tree, Quassia amara. Extracts of this wood have long been used as an insecticide.

In summary, we have examined numerous plant extracts and natural products as possible spruce budworm larval feeding deterrents in laboratory bioassays. The most active plant extracts were those known to contain alkaloids. All of the highly active compounds we have found, with the exception of quassin, are alkaloids. Due to high mammalian toxicity, none of the alkaloids may prove to have direct potential for field application. There are, however. very specific structural requirements for activity in these systems and, as we learn more about the relationship between structure and activity, we hope to be able to design molecules with high deterrent activity and low toxicity.

TABLE I. Plant Extracts Assayed as Deterrents for Spruce Budworm Feeding.

Scientific Name	Common Name	Plant* Part	Activity* Range
Acer platanoides	Norway maple	L	I
Achillea millefolium	yarrow	L	MD
Actaea rubra	red baneberry	L	I
Allium cepa	Egyptian onion	L	I
Allium schoenoprasum	chive	L	MD
Alnus crispa	green alder	L	I
Aloe sp.	aloe	L	I
Anethum graveolens	dill	L	I
Antirrhinum sp.	snapdragon	R,L	MD
Apocynum sp.	dogbane	L	D
Arisaema atrorubens	jack-in-the-pulpit	R	I
Artemesia absinthium	wormwood	L	D
Ascophyllum nodosum	rockweed	L	D
Calendula officinalis	marigold	L,F	D
Catalpa sp.	catalpa	B,F	I
Chenopodium album	lamb's quarters	L	I
Chrysanthemum leucanthemum	ox-eye daisy	L	I
Clorophytum sp.	spider plant	L	I
Coleus blumei	coleus	L	I
Comptonia peregrina	sweet fern	L	MD
Convolvulvus arvensis	lesser bindweed	F,L	MD
Cornus stolonifera	red osier dogwood	L	MD
Crassula argentea	jade plant	L	I

TABLE I. (Cont'd.)

Scientific Name	Common Name	Plant* Part	Activity* Range
Crataegus sp.	hawthorn	L	I
Digitalis purpurea	foxglove	L	I
Dryopterus sp.	fern	L	D
Eleocharis sp.	spike rush	L	I
Epilobium angustifolium	fireweed	R,L,F,	I
Equisetum pratense	common horsetail	L	I
Eupatorium sp.	Joe-pye weed	L	I
Euphorbia pulcherrima	poinsettia	L	MD
Euphorbia splendens prostrata	crown of thorns	L	I
Fraxinus pennsylvanica	green ash	L,S	MD
Galium sp.	Bedstraw	L	I
Gasteria sp.	gasteria	L	I
Hedera sp.	ivy	L	I
Helianthus annuus	sunflower	L	MD
Hemerocallis fulva	day lily	L	I
Hisbiscus sp.	hisbiscus	L	I
Hieracium aurantiacum	orange hawkweed	L	I
Hoya carnosa	hoya	L	MD
Hypericum perforatum	St. John's wort	R,F,L	D
Impatiens sp.	impatiens	L	MD
Iris sp.	iris	L	I
Juniper communis depressa	juniper	L	MD
Kalanchoe sp.	kalanchoe	L	MD
Linaria vulgaris	butter and eggs	R	MD

TABLE I. (Cont'd.)

Scientific Name	Common Name	Plant* Part	Activity* Range
Lupinus polyphyllus	lupine	S,L	HD
Lychnis flos-cuculi	ragged robin	L,F	I
Lycopersicum esculentum	tomato	L	HD
Lysimachia ciliata	fringed loosestrife	L	MD
Lysimachia terrestris	yellow loosestrife	L	I
Lythrum salicaria	purple loosestrife	L	D
Maianthenum canadense	lily of the valley	L	I
Matricaria matricarioides	pineapple weed	L	MD
Mentha sp.	mint	L	I
Myrica gale	sweet gale	L	I
Nasturtium sp.	nasturtium	L	I
Nepata cateria	catnip	L	D
Nephrolepis exaltata	Boston fern	L	MD
Nerium oleander	oleander	L	MD
Ocymum basilicum	basil	L	D
Onoclea sensibilis	sensitive fern	L	MD
Paeonia sp.	peony	L	MD
Pelargonium sp.	geranium	L	MD
Pelargonium sp.	lemon geranium	L	I
Pelargonium sp.	ivy-leaf geranium	L	I
Peperomia sp.	peperomia	L	I
Petunia sp.	petunia	L	I
Philodendron sp.	philodendron	L	I

TABLE I. (Cont'd.)

Scientific Name	Common Name	Plant* Part	Activity* Range
Phleum pratense	timothy	L	MD
Pinus nigra	black pine	L	I
Pinus resinosa	red pine	L	I
Pinus strobus	white pine	L	I
Pinus sylvestris	Scotch pine	L	I
Plantago major	common plaintain	L	MD
Potentilla anserina	silver weed	L	MD
Prunella vulgaris	wound wort	L	MD
Pteridium aquilinum	bracken fern	L	I
Pyrola elliptica	shinleaf	L	I
Quercus alba	white oak	L	I
Quercus rubra	red oak	L	I
Rheum rhaponticum	rhubarb	S,L	D
Rhinanthus crista-galli	yellow rattle	L,F	MD
Rhus typhina	staghorn sumac	L	I
Sagittaria sp.	arrowhead	L	MD
Salix, sp.	willow	B	MD
Salvia officinalis·	sage	L	D
Schefflera actinophylla	umbrella tree	L	I
Sedum telephium	live-forever	L	MD
Sium suave	water parsnip	R,L	I
Solanum dulcamera	nightshade	L,F,R	HD
Solanum pseudocapsicum	Jerusalem cherry	L	D
Solanum tuberosum	potato	L	HD

TABLE I. (Cont'd.)

Scientific Name	Common Name	Plant* Part	Activity* Range
Solidago sp.	goldenrod	L	I
Tanacetum vulgare	tansy	L	D
Taraxacum officinale	dandelion	L	I
Thalictrum polygamum	tall meadow rue	L	I
Thuja occidentalis	northern white cedar	L	I
Tradescantia sp.	spiderwort	L	I
Trifolium pratense	red clover	L	MD
Tsuga canadensis	hemlock	L	MD
Tussilago farfara	coltsfoot	R	HD
Urtica dioica	stinging nettle	MD	I
Valeriana officinalis	valerian	L,R,F	HD
Verbascum thapsus	mullein	R	MD
Viola sp.	violet	L	I
Vicia cracca	canada pea	L	MD
Zebrina sp.	wandering Jew	L	MD

* HD = >75% deterrency
D = >50% deterrency
MD = >25% deterrency
I = <25% deterrency

L Leaf
R Root
F = Flower
B = Bark
S Stem

TABLE II. Compounds Assayed as Spruce Budworm Feeding Deterrents

Compound	Concentration (mg/ml)	Activity Range*
Pyrrolizidine Alkaloids		
senkirkine	0.5	HD
lasiocarpine	"	HD
monocrotaline	"	I
echinitine	"	I
retronecine	"	I
europine-n-oxide	"	I
neosenkirkine	"	I
7 hydroxyheliotridane	"	I
heliotrine	"	MD
crispatine	"	D
otosenine	"	I
echinatine-n-oxide	"	I
senecionine	"	MD
europine	"	I
Solanum Alkaloids		
tomatidine	0.4	D
tomatine	1	HD
solanidine	0.4	D
α - solanine	.9	D
α - chaconine	.9	HD

TABLE II. (Cont'd.)

Compound	Concentration (mg/ml)	Activity Range*
Quinolizidine Alkaloids		
lupinine	0.5	I
epilupinine	0.5	I
angustifoline	0.5	I
17 oxolupanine	0.5	I
sparteine	0.5	D
α- isolupanine	0.5	I
tetrahydrorhombifoline	0.5	I
cytisine	0.5	I
lupanine	0.5	I
13 lupanylbenzoate	0.5	HD
13 lupanyltiglate	0.5	HD
13 lupanylcinnamate	0.5	HD
lupinyl trans-cinnamate	0.5	I
Hydroxamate Peptides		
rhodotorulic acid	0.5	I
desferrichrome C	0.9	I
desferricrocin	3	I
desferal mesylate	.7	I
Coumarins		
oroselone	2.3	I
umbelliferone	2	I

TABLE II. (Cont'd.)

Compound	Concentration (mg/ml)	Activity Range*
Coumarins		
4 methylumbelliferone	2	I
Benzofurans		
methoxyeuparin	2.5	I
homoegonol	3.4	I
acamelin	1.8	I
isopterofuran	4	I
Miscellaneous		
sesamin	2	MD
widdrol	2	MD
hinokiic acid	2	I
savinin	2	D
sawaranin	2	I
cedrol	2	I
berberine	0.4	MD
quassin	2	D
5β -androstan-3α-ol-17-one	0.5	I
5α-androstan-3α-ol-17-one	0.5	I
ethyl cinnamate	0.5	I
emodin	10	MD
p-hydroxyacetophenone	10	D

TABLE II (cont'd.)

	Miscellaneous	
brucine	5	HD
schisanhenol	3	D

* HD = > 75% deterrency

D = > 50% deterrency

MD = > 25% deterrency

I = < 25% deterrency

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