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fescue is not to be mowed in a rough turf, Embark (mefluidide) will suppress seedheads for a longer period of time than Primo (CGA 163935) (5,6).

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Suitability of Juniper Cultivars for Survival and Growth of the Bagworm[1]

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Abstract

Relative suitability of 23 cultivars of juniper (*Juniperus* spp.) for growth and survival of the bagworm, *Thyridopteryx ephemeraeformis* (Haworth) was evaluated in laboratory and field experiments. Weight gain, developmental rate, and survival of bagworms differed significantly among groups of larvae fed foliage from different cultivars. By these criteria, cultivars 'Expansa' and 'Hibernica' were most unsuitable for survival and development of bagworms, whereas 'Broadmoor' and 'Emerald Isle' were consistently among the most suitable cultivars. This study suggests that use of certain juniper cultivars may be useful in managing this perennial insect pest in urban landscapes.

Index words: *Thyridopteryx ephemeraeformis, Juniperus*, host plant resistance.

Significance to the Nursery Industry

Breeding programs for woody landscape plants have historically placed greater emphasis on desirable aesthetic characteristics than resistance to insect pests. Evaluations for cultivar resistance have been made for relatively few plant or pest species. This study suggests that cultivars of juniper differ in their suitability as hosts for the bagworm, a common pest of evergreen landscape plants. Use of relatively less suitable cultivars could help to reduce the need for insecticide use on junipers in nursery and landscape settings.

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Introduction

The bagworm, *Thyridopteryx ephemeraeformis* (Haworth) (Lepidoptera: Psychidae), is a common pest of landscape and nursery plants east of the Rocky Mountains. The bagworm feeds upon at least 120 plant species, but is particularly damaging to juniper (*Juniperus* spp.), arborvitae (*Thuja occidentalis* L.) and blue spruce (*Picea pungens* Engelm.). Outbreaks are frequent but can be locally severe, with total defoliation and death of trees (1).

Few studies have investigated possible sources of host plant resistance to bagworms. Sheppard (6), who measured larval development on spruce, pine, maple and oak foliage, concluded that bagworms generally grew faster, weighed more, and had higher survival on the coniferous than on the deciduous hosts. Neal and Santamour (2) found that arborvitae and black locust (*Robinia pseudoacacia* L.) were more favorable for development of bagworms than were eastern white pine (*Pinus strobus* L.), honeylocust (*Gleditsia triacanthos* L.), and sycamore (*Plantanus occidentalis* L.).

There has, however, been almost no research to determine if particular cultivars of woody landscape plants vary in resistance to bagworms. The objective of our study was to compare the development and survival of bagworms on foliage of 23 commonly used juniper cultivars. Identification of cultivars that are relatively less susceptible to bagworms

could be helpful in reducing the need for use of insecticides in nursery and landscape settings.

Materials and Methods

Twenty-three cultivars of *Juniperus* spp. (Table 1) representing a range of commonly planted genotypes and growth forms were obtained from commercial nurseries and from the University of Kentucky Horticulture Department in late winter, 1991. At the time of planting, the age and height of the experimental plants ranged from 1 to 4 yrs, and from 0.15 m (0.5 ft) to 1.2 m (4.0 ft), respectively. The trees were planted in a common plot on a Maury silt loam soil at the University of Kentucky's South Farm, Lexington. Cultivars were arranged in a randomized complete block design. Spreading-type plants (17 cultivars) were planted in rows 3.1 m (10.0 ft) apart with 0.9 m (3.0 ft) spacing between plants in rows. Upright-type plants (6 cultivars) were planted 3.1 m (10.0 ft) apart between and within rows. There were 10 replicates of each cultivar except for 'Blue Mat,' 'Emerald Sea' and 'Spartan,' for which only five plants could be obtained. Plants were mulched with wood chips, watered at the time of planting, and as needed thereafter.

Laboratory Evaluation. Rearing Tests, 1991–92. Female bags with overwintering egg masses were gathered from landscape plants, mainly cultivated junipers, in Lexington, KY in April and early May of each year. The bags were placed outdoors in screened cages in partial shade until the eggs had begun to hatch and neonate larvae emerged from the bags. Fresh shoots, 10 cm (4 in) long with new and 1 yr old foliage, were collected from each of the experimental plants, placed in plastic bags, and taken in a cooler to the laboratory. The shoot samples from two plants of a particular type were randomly pooled to provide five replicates per cultivar, except in the case of the three cultivars for which only five plants were available. The samples for these cultivars each came from a separate, individual plant.

In 1991, the shoot samples were placed on damp filter paper in circular, unventilated clear plastic containers (15.5 cm (6.1 in) diam, 4 cm (1.6 in) height). Ten newly-hatched (< 1 day old) larvae were transferred to the foliage in each container using a fine brush. Plant material was replaced with fresh shoots from the original plants as needed. The larvae were never food-limited. Containers for each cultivar were stacked together in a walk-in growth chamber with 16:8 h (L:D) photoperiod, with day and night temperatures of 26.7°C (80°F) and 23.3°C (74°F), respectively. An empty, filter paper-lined container was placed on top of each stack to equalize light intensity for all replicates. Containers were rotated daily to minimize any bias that might be associated with position in the growth chamber. After 4 wks, all surviving bagworms from each replicate were removed from their bags, weighed live, and preserved in 70% ethanol. Larval instar, an indicator of developmental rate, was determined by measuring the head capsule width of each bagworm with an ocular micrometer in a binocular microscope.

Table 1. Cultivars of *Juniperus* sp. evaluated for relative resistance to bagworms.

Juniperus chinensis 'Mint Julep'
Juniperus chinensis 'Pfitzeriana'
Juniperus chinensis 'Saybrook Gold'
Juniperus chinensis 'Hetzii'
Juniperus chinensis 'Keteleeri'
Juniperus chinensis sargentii 'Viridis'
Juniperus chinensis 'Spartan'
Juniperus communis 'Hibernica'
Juniperus conferta 'Blue Pacific'
Juniperus conferta 'Emerald Sea'
Juniperus davurica 'Expansa' (Parsoni)
Juniperus horizontalis 'Bar Harbor'
Juniperus horizontalis 'Blue Chip'
Juniperus horizontalis 'Blue Mat'
Juniperus horizontalis 'Blue Rug/Wiltoni'
Juniperus horizontalis 'Emerald Isle'
Juniperus horizontalis 'Prince of Wales'
Juniperus horizontalis plumosa 'Andorra'
Juniperus horizontalis plumosa compacta 'Youngstown'
Juniperus sabina 'Broadmoor'
Juniperus scopulorum 'Skyrocket'
Juniperus copulorum 'Wichita Blue'
Juniperus squamata 'Blue Star'

The experiment was repeated in 1992. We used screened lids on the rearing containers to improve ventilation and to help to reduce mortality of small larvae, a few of which drowned in condensed moisture in the 1991 test. Wire spacers were placed between the stacked containers to allow air circulation. In each year, weights of surviving larvae and instars attained were averaged within containers; numbers of survivors and average larval weight and instar attained were subjected to analysis of variance (ANOVA) followed by the Ryan-Einot-Gabriel-Welsch multiple range test (REGWQ) (3) to separate the means when differences among the cultivars were significant ($P < 0.05$). Frequency distributions of larval instars after 4 wks were subjected to chi-square analysis to test for homogeneity of proportions among cultivars. Cultivars having proportionately more older or younger larvae are considered to be respectively more or less suitable for bagworms.

Non-preference Tests, 1991–92. Fresh 10 cm (4 in) shoots were harvested from four randomly-selected plants of each cultivar as described for the rearing tests. Shoots were placed on moist filter paper in plastic containers as before. Two concentric rings of Tree Tanglefoot (The Tanglefoot Co., Grand Rapids, MI) were placed around the perimeter of the filter paper to entrap any larvae leaving the foliage. Preliminary tests showed that the second ring was necessary to trap larvae that used another trapped larva as a bridge to cross over the inner barrier. Ten newly-hatched larvae were placed on the foliage sample within each container. Numbers of larvae remaining on the foliage versus those off of the foliage or caught in the rings were counted after 48 h. Numbers of larvae accepting (i.e., on the foliage) or rejecting (i.e., wandering or caught) a particular cultivar were converted to percentages. Data were then subjected to arcsin transformation followed by ANOVA, and means were separated by the REGWQ tests as described before.

Cultivars 'Mint Julep,' 'Viridis,' 'Blue chip,' 'Blue Mat,' 'Blue Rug,' 'Prince of Wales,' 'Andorra' and 'Broadmoor' were not included in the 1991 test because of insufficient numbers of available larvae. Also, there were only enough larvae to run two replicates of 'Pfitzeriana.' Methods differed slightly in the 1992 test, where all cultivars were included and in which five larvae were placed on each replicate.

Field Evaluations, 1991–92 Ten newly hatched larvae were transferred to each of the field plants (except cv. 'Broadmoor,' which was left uninfested due to small plant

size) on May 20–21, 1991. The unrestricted larvae were allowed to feed for 9 wks, after which the trees were carefully examined and all bagworms were removed. Surviving larvae were counted, individually weighed, and measured for determination of larval instar.

Because of poor recovery of larvae in the 1991 test, in 1992 the larvae were confined in fine mesh bags (15 × 30 cm; 6 × 12 inch) which were placed over the shoots of the test plants. Ten newly-hatched bagworms were transferred to small plastic cups in the laboratory and transported to the field. Cups were opened inside the mesh bags before the bags were secured at their base with a wire twist-tie. Wire hardware cloth supports were placed under bags on spreading type cultivars to prevent them from touching the soil and to allow drainage and ventilation. After 4 wks, all surviving larvae were counted, removed from their bag, and weighed and measured as before. Data were analyzed in the same manner as for the laboratory tests.

Results and Discussion

Laboratory Evaluation. Laboratory Rearing Tests, 1991–92. Larval weight and survival after 4 wks differed significantly among cultivars in the 1991 test (Table 2). Larvae reared on 'Spartan' and 'Blue Pacific' weighed significantly less than those on 'Broadmoor' and 'Bar Harbor.' Cultivars 'Hibernica,' 'Expansa,' 'Pfitzeriana' and 'Wichita Blue' also produced significantly lower weights than 'Broadmoor.' After 4 wks there were significantly fewer larvae surviving on 'Blue Star' than on any other cultivar (Table 2).

Table 2. Growth and survival of bagworms reared on juniper foliage for 4 wk in the laboratory, and relative acceptability of foliage on selected cultivars, 1991.

	Rearing study			
Cultivar	Mean larval weight (mg)[z]	Mean % survival	Mean instar attained	Mean % accepting foliage[y]
Spartan	299c	66ab	4.54bc	39b
Blue Pacific	342c	77ab	4.38c	85ab
Hibernica	358bc	74ab	4.62abc	78ab
Expansa	406bc	72ab	4.74abc	95a
Pfitzeriana	499bc	66ab	4.90abc	84ab
Wichita Blue	509bc	79ab	4.80abc	87a
Blue Chip	558abc	52ab	5.02abc	—
Mint Julep	576abc	82ab	5.00abc	—
Youngstown	582abc	81ab	5.00abc	83ab
Blue Star	583abc	15c	5.13abc	73ab
Saybrook Gold	611abc	72ab	5.14abc	78ab
Emerald Sea	634abc	79ab	5.08abc	74ab
Hetzii	645abc	88a	4.82abc	81ab
Prince of Wales	714abc	52ab	5.20abc	—
Skyrocket	722abc	82ab	5.32abc	68ab
Blue Mat	724abc	74ab	5.52ab	—
Emerald Isle	789abc	75ab	5.26abc	93a
Blue Rug	790abc	48b	5.12abc	—
Keteleeri	860abc	72ab	5.60a	52ab
Viridis	891abc	75ab	5.32abc	—
Andorra	894abc	76ab	5.34abc	—
Bar Harbor	957ab	58ab	5.42ab	85ab
Broadmoor	1119a	62ab	5.54ab	—

[z]Means with identical letters within a column are not significantly different (P > 0.05; REGWQ Test [SAS Institute, 1988]).

[y](—) denotes cultivars not included due to shortage of larvae.

There were 793 total larvae surviving after 4 wks in 1991, with fifth instars the most common developmental stage represented (369 larvae). Only one second instar, and 17 third instar larvae were found, so instars 2–4 were combined for analysis. Eight cultivars showed significant deviation ($\chi^2 > 6.63$; df = 1; $P < 0.01$) from the overall ratio of instars for all cultivars combined. 'Blue Mat,' 'Keteleeri,' 'Broadmoor' and 'Andorra' had proportionately more sixth instars, indicating faster development and greater suitability. Conversely, cultivars 'Hetzii,' 'Blue Pacific,' 'Spartan' and 'Hibernica' had proportionately more small bagworms, e.g., fourth or fifth instars, suggesting relative unsuitability. Relatively faster or slower development on particular cultivars is also reflected by differences in mean larval instar attained (Table 2).

In 1992, there were significant differences among juniper cultivars for larval weight and percent survival (Table 3). As in the previous year, 'Broadmoor' was particularly favorable for growth of bagworms. Surprisingly, 'Blue Pacific' and 'Spartan,' two of the poorest cultivars in the 1991 test, supported rapid growth of bagworms in 1992 (Table 3). Reasons for this difference are unknown. Survival ranged from 80% on 'Wichita Blue' and 'Blue Pacific' to only 33% on 'Youngstown.' Only three replicates of 'Bar Harbor' and 'Hibernica' and four replicates of 'Mint Julep' and 'Youngstown' had surviving larvae after 4 wks.

Most (510) of the 632 total larvae surviving after 4 wks were fourth and fifth instars. Only five second instars were found; second and third instars were therefore combined before analysis. Ten cultivars showed significant deviation from the overall frequency distribution of instars for all cultivars combined ($\chi^2 < 6.63$; df = 1; $P < 0.01$). Cultivars

Table 3. Growth and survival of bagworms reared on juniper foliage for 4 wk in the laboratory, and relative acceptability of foliage, 1992.

	Rearing study			
Cultivar	Mean larval weight (mg)[z]	Mean % survival	Mean instar attained	Mean % accepting foliage
Youngstown	41c	33c	3.33d	84a
Mint Julep	86bc	35bc	3.70cd	65a
Viridis	101bc	66abc	3.80bcd	72a
Expansa	112bc	40abc	3.98abcd	60a
Hibernica	120bc	37bc	4.00abcd	72a
Blue Rug	124bc	60abc	3.94bcd	96a
Prince of Wales	124bc	40abc	3.66cd	84a
Blue Chip	141bc	48abc	4.00abcd	72a
Hetzii	147bc	72abc	4.04abcd	76a
Andorra	149bc	62abc	3.86bcd	96a
Bar Harbor	162bc	47abc	4.60abc	96a
Skyrocket	196bc	62abc	4.50abcd	72a
Keteleeri	200bc	64abc	4.44abcd	84a
Pfitzeriana	213bc	50abc	4.46abcd	88a
Saybrook Gold	219bc	70abc	4.24abcd	80a
Wichita Blue	228bc	80a	4.90ab	84a
Emerald Sea	292bc	68abc	4.54abc	64a
Blue Star	317bc	68abc	4.76abc	68a
Blue Mat	317bc	50abc	4.50abcd	76a
Emerald Isle	351bc	76ab	4.76abc	88a
Spartan	413bc	56abc	4.56abc	84a
Blue Pacific	450ab	80a	4.92ab	88a
Broadmoor	738a	58abc	5.16a	88a

[z]Means with identical letters within a column are not significantly different (P > 0.05; REGWQ Test [SAS Institute, 1988]).

'Andorra,' 'Prince of Wales,' 'Youngstown,' 'Expansa' and 'Viridis' had relatively more third and fourth instars, suggesting poor host suitability, whereas 'Blue Star,' 'Emerald Isle,' 'Wichita Blue,' 'Blue Pacific,' and 'Broadmoor' had proportionately more fifth or sixth instars, suggesting that they are relatively good hosts. Mean larval instar attained also differed among cultivars (Table 3). Larval weights were lower at the conclusion of the 1992 study than in 1991. This may have been due to ventilation of the containers in 1992, which reduced humidity and apparently created a less favorable environment for growth of the larvae.

Non-preference Tests, 1991–92. The percentage of larvae remaining on the foliage differed significantly among cultivars in 1991. Acceptance ranged from 93 to 95% for 'Emerald Isle' and 'Expansa,' respectively, to only 39% on 'Spartan' (Table 2). However, there were no significant differences among cultivars in the 1992 test (Table 3).

Field Evaluations, 1991–92. The 1991 field study was inconclusive because of very low numbers of surviving larvae. Of the 2050 original bagworms placed on 205 plants of 22 juniper cultivars in the field, only 33 larvae were recovered on nine cultivars. Most (30) of the recovered larvae were on cultivars with upright growth habit, including 'Wichita Blue' (11), 'Keteleeri' (7), 'Skyrocket' (6), 'Hetzii' (4), 'Hibernica' (1) and 'Spartan' (1). Only three larvae were recovered from spreading type junipers, one each for 'Andorra,' 'Mint Julep' and 'Youngstown.'

In 1992, recovery of larvae in the mesh bag enclosures was greatly improved. Mean larval weights differed significantly among cultivars, ranging from 44 mg on 'Broadmoor' to ≤ 20 mg/larva on 'Wichita Blue,' 'Hibernica,' 'Keteleeri' and 'Skyrocket' (Table 4). Survival also differed significantly among cultivars. Most (849) of the 1291 larvae recovered from the field experiment were third instars. Only one first instar was recovered; this was combined with second instars before analysis. Five cultivars, 'Hetzii,' 'Hibernica,' 'Keteleeri,' 'Skyrocket' and 'Wichita Blue' supported proportionately more second instars ($\chi^2 > 6.63$; df = 1; $P < 0.01$), suggesting slower development and relatively greater resistance, whereas 'Broadmoor' and 'Emerald Isle' supported fewer early instars and proportionately more fourth instars, indicating greater host suitability. Mean larval instar attained also differed among cultivars (Table 4). Survivorship ranged from 89% on 'Blue Pacific' to 42 and 40% on 'Spartan' and 'Blue Star' respectively (Table 4).

For caterpillars, a longer developmental period increases the risks of exposure to biotic (e.g., predation, parasitism, pathogens) and abiotic (e.g., weather) mortality agents (4). Moreover, because there is usually a good correlation between final body weight and adult fecundity (5), development on inferior hosts can carry significant fitness costs (e.g., reduced clutch sizes). It is also possible that bagworms developing on inferior host cultivars may be unable to reach sufficient size for pupation, emergence and mating by late summer or early fall.

Although our study suggests that none of the 23 juniper cultivars we evaluated is completely resistant to the bagworm, we did find significant differences in their suitability for growth and survival of bagworm larvae. Performance of bagworms on particular cultivars varied from trial to trial. By separating the six cultivars resulting in the highest or lowest larval weights and survival in each of the three complete

Table 4. Growth and survival of bagworms reared on juniper foliage for 4 wk in the field, 1992.

	Rearing study		
Cultivar	Mean larval weight (mg)[z]	Mean % survival	Mean instar attained
Skyrocket	18h	54abcd	2.27e
Keteleeri	19gh	43cd	2.31de
Hibernica	19gh	53abcd	2.29e
Wichita Blue	20fgh	49bcd	2.58bcde
Expansa	22efgh	63abcd	2.88abc
Andorra	23defgh	62abcd	2.76abcde
Youngstown	23defgh	66abcd	2.78abcde
Spartan	23defgh	42d	2.82abcd
Blue Chip	24defgh	66abcd	2.83abc
Mint Julep	24defgh	74abcd	2.66abcde
Hetzii	25defgh	50bcd	2.52cde
Saybrook Gold	26cdefgh	67abcd	2.66abcde
Viridis	27bcdefgh	69abcd	2.92abc
Bar Harbor	28bcdefgh	70abcd	2.88abc
Blue Star	30bcdefg	40d	2.88abc
Prince of Wales	31bcdef	78abcd	3.07ab
Emerald Sea	31bcdef	50bcd	2.58bcde
Pfitzeriana	33abcde	67abcd	2.88abc
Emerald Isle	34abcd	66abcd	3.11ab
Blue Rug	37abc	81abc	3.07ab
Blue Mat	37abc	82ab	2.96abc
Blue Pacific	38ab	89a	2.74abcde
Broadmoor	44a	70abcd	3.15a

[z]Means with identical letters within a column are not significantly different ($P > 0.05$; REGWQ Test [SAS Institute, 1988]).

experiments (1991 and 1992 laboratory, 1992 field), we identified cultivars that were consistently among the most suitable or unsuitable hosts. Growth and survival of bagworms was generally poor on cultivars 'Expansa,' 'Hibernica,' 'Wichita Blue,' and 'Keteleeri.' 'Expansa' was in the bottom six in five of the six comparisons and 'Hibernica' was in the bottom six in four of the comparisons. Neither cultivar appeared in the top six in any of the studies. Three of these four cultivars are upright types. Two cultivars that were consistently among the most suitable hosts were 'Broadmoor' and 'Emerald Isle.' Both cultivars were in the top six in four of the six comparisons and neither was ever in the bottom six. Three other highly suitable hosts were 'Blue Pacific,' 'Blue Rug,' and 'Blue Mat.' Interestingly, all of these cultivars are spreading types.

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