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Risk of Phytotoxicity of Sawdust Substrates for Greenhouse Vegetables

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Abstract

The use of forestry wastes based substrates for greenhouse production constitutes a sustainable alternative to largely used inorganic or peat substrates. Our recent studies have shown benefits of using *Picea glauca* sawdust/composted bark based substrates compared to rockwool in terms of reducing production costs with equivalent or higher yield and root growth. However, in addition to their specific physical properties, forestry waste products can contain phytotoxic compounds such as manganese, heavy metals, terpenes and phenols. These compounds can have serious consequences owing to the direct root contact with the concentrated form. Phytotoxic molecules can be detected and quantified by complex analytic methods, while bio-assays are rapid, economic and include known and unknown toxic compounds. Therefore, this study was intended to evaluate the phytotoxicity risk of fresh sawdusts and sawdust species mixture substrates on greenhouse vegetable crops (tomato, cucumber and sweet pepper) by biotests. Ten tree species have been selected according to the usual byproducts of the Canadian forest industry (*Abies balsamea*, *Picea* sp., *Pinus* sp., *Thuja* sp., *Chamaecyparis nootkatensis*). Plant biomass, leaf area and *Chl a* fluorescence parameters were measured after 3-5 weeks of growth depending on the crop. The experimental design was a complete bloc with ten replicates (3 pots of 10 cm diameter per e.u.) including positive (peat/perlite substrate) and negative controls (peat/perlite substrate + dichlobenil). Our results have shown that *Thuja* sp. based substrates were phytotoxic for tomato, cucumber and pepper seedlings, while other tree species did not reduce plant biomass and leaf area. The F_v/F_m ratio was not a good indicator of the plant phytotoxicity.

INTRODUCTION

Since the last 20 years, concerns about environmental pollution by the greenhouse industry have been stressed by environmental groups. Problems associated with the acquisition, production and disposal of materials used as growing media have been identified: 1) use of semi-finite resources (peat), 2) energy consumption in manufacture (rockwool, perlite, vermiculite), and 3) stability of inorganic materials such as rockwool. The depletion of certain types of peat land habitats has also been identified as a threat by environmental groups (Carlile, 1999). Replacement of rockwool and peat in growing media by local, affordable and more readily renewable materials, with appropriate physical and chemical properties, is now a worldwide target. These substitutes should ideally be made of industrial by-products or waste products derived from renewable resources. From that point of view, wood by-products are renewable, cheap, and widespread geographically. Used in combination with peatmoss and biosolids, composted or none composted wood waste have been the mainstays of the nursery industry over the last 30 years. On the other hand, pure or mixed sawdust have also been used successfully for greenhouse vegetables when appropriate irrigation and nutritional management strategies were provided (Portree, 1996; Dorais et al., 2005; Allaire et al., 2005). However, forestry waste products (barks, sawdust, wood chips, wood composts) can contain phytotoxic compounds such as manganese, heavy metals, terpenes and phenols (Still et al., 1976; Aaron, 1982; Ortega et al., 1996). These compounds can have serious consequences owing to the direct root contact with the concentrated form if no pre-washing treatments have been done. For example, water extracts of fresh silver maple bark (*Acer saccharinum* L.) inhibited root elongation of cucumber due to phenolic compounds (Still et al., 1976). Washing process with cold (15°C) and hot (70°C) water decreased free phenolic acid contents of oak cork and improved seedling growth compared to control seedlings grown on none washed cork (Ortega et al., 1996). Germination and radicle growth of tomato and lettuce are sensitive to phenolic compounds from oak bark (*Quercus suber* L.), while seedling growth reduction was observed for tomato, pepper, cucumber, lettuce, cauliflower, Chinese cabbage and watermelon grown in cork oak bark substrate compared to Sphagnum peats (Ortega et al., 1996). For seven ornamental species, Nichols (1981) observed that fresh *Pinus radiata* bark impaired the growth of some species but did not affect others. Similarly to pine bark, pine chips (*Pinus taeda*), which have different physical and chemical properties (porosity, water holding capacity and CEC) also offer potential as a container substrate for Japanese holly, azalea, and marigold (Wright and Browder, 2005).

From a practical and economical point of view, analytic techniques to detect and quantify phytotoxic molecules from a large number of growing media is not feasible. Consequently, several phytotoxicity bioassays have been proposed based on germination rate and root growth of sensitive plants, either on the product itself or on a water extract (Still et al., 1976; Nichols, 1981; Zucconi et al., 1981; Moreno et al., 1999). However, such tests with sensitive species may overestimate the risk of toxicity in real growing conditions (Nichols, 1981) and be useless for other species (Ortega et al., 1996). For that reason, biotests based on plant growth have been proposed by several authors (Still et al., 1976; Morel and Guillemain, 2004). On the other hand, few rapid and none destructive phytotoxic indicators have been proposed for seedlings and mature plants. Therefore, this study was intended 1) to evaluate the phytotoxicity risk of fresh sawdusts from ten tree species selected according to the usual by-products of the Canadian forest industry on greenhouse vegetable crops by bioassays, and 2) to assess if *Chl a* fluorescence parameters can be used as indicators of plant phytotoxicity.

MATERIAL AND METHODS

Plant Material

The three most important greenhouse vegetables grown in Canada were studied: *Lycopersicon esculentum* L. 'Trust' (Norseco), *Cucumis sativus* 'Bodega' (Rijk Zwaan), and *Capsicum annum* 'Triple 4' (Enza Zaden). Seeds were sown on rockwool blocks (1.58 cm x 1.58 cm x 2.54 cm), placed in growth chambers (23°C day/21 to 23°C night, 80% RH, PPF of 400 µmol m^{-2} s^{-1}, photoperiod of 16 hours) and daily irrigated with a complete nutrient solution (Portree, 1996). After 15 to 24 days, seedlings were transplanted in 10 cm plastic pots (380 ml volume).

Growing Media

Ten tree species have been selected according to by-products usually found in the Canadian forest industry: *Abies balsamea*, *Picea glauca*, *Picea mariana*, *Pinus strobes*, *Pinus banksiana*, *Pinus resinosa*, *Thuja plicata*, *Thuja occidentalis*, *Chamaecyparis nootkatensis*. Mixes of *Abies balsamea* and *Picea glauca* were also studied in different proportions (20:80, 40:60, 60:40 and 80:20) as found in the industry, depending of the region. Fresh sawdust was used with particle size of 1 to 6 mm. The control medium used was a mix of 80% peat and 20% perlite (v/v). A negative peat:perlite control with 14 mg L^{-1} dichlobenil was used according to Morel and Guillemain (2004).

Experimental Design

Trial 1 and 2 were made up of 5 replicates of 10 and 8 treatments respectively (3 pots per e.u., 150 and 120 plants per species for Trial 1 and 2, respectively). The experimental design for both trials was a complete randomized block. ANOVA and then mean separations were performed using the protected LSD test available in SAS stat software v.8.2. (SAS Institute, Cary, NC).

Growth Parameters

Fresh and dry biomass, leaf area, leaf number and *Chl a* fluorescence parameters (PEA, Hansatech, Norfolk, UK) were measured after 3-5 weeks of growth depending on the crop, and compared to the positive and negative controls.

RESULTS AND DISCUSSION

Although *Pinus resinosa* had a negative effect, *Thuja* sp. based substrates were especially phytotoxic when used to grow cucumber. Leaf area, shoot biomass FW as well as DW were decreased significantly ($P<0.05$) by 55, 45 and 51% respectively as compared to positive control (Tables 1 to 3). *Abies* and *Picea* species and mixtures did not reduce plant biomass and leaf area of greenhouse vegetable seedlings. *Picea mariana* and *Chamaecyparis nootkatensis* gave high leaf area and number as well as shoot biomass (FW and DW) for all plant species.

Mean *Chl a* fluorescence parameter Fv/Fm ratio were 0.829 and 0.840 for tomato, 0.790 and 0.796 for pepper and 0.801 and 0.744 for cucumber respectively for Trials 1 and 2. However, mean performance index (PI) was lower for cucumber as compared to the other plant species for both Trial 1 and 2 (cucumber 1.3 and 0.6; tomato 2.6 and 3.4; pepper 1.7 and 2.3). These results were however not an indication of a phytoxicity caused by a specific type of substrate (data not shown).

CONCLUSION

Results from this study demonstrate the feasibility of growing greenhouse vegetables in sawdust derived from a large number of softwood Canadian species. Except for *Thuja* sp., no risk of phytotoxicity has been detected for tomato, pepper and cucumber. On the other hand, appropriate irrigation strategies for such substrates should be adapted as reported by Dorais et al. (2005) and Allaire et al. (2005) due to their specific physical properties (AFP, Ds/Do, EWA), and correlations with yield.

In these trials the Fv/Fm ratio or PI were not good indicators of substrate phytotoxicity. Visual symptoms of phytotoxicity were not observed, this could explain the relatively high values of Fv/Fm. PI values did not help discriminate phytotoxicity effects of substrates on plant species. Longer trials may be needed in order to use *Chl a* fluorescence parameters as phytotoxicity indicators.

Thuja sp. based substrates were phytotoxic for tomato, cucumber and pepper seedlings, while other tree species and mixtures did not reduce plant biomass and leaf area. Sawdust based substrates improved air filled porosity compared to peat and rockwool substrates and increased root development. Further investigations should be done to identify quick, none destructive and easy phytotoxicity indicators for short and long terms crops.

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Tables

Table 1. Effects of sawdust substrates on tomato growth parameters after 5 weeks of treatment.

	Leaf area (cm^2)	Shoot biomass (g FW)	Shoot biomass (g DW)	%DW	Leaf number	FV/FM
Trial 1						
Picea mariana	1289.2 a	95.7 a	8.4 a	8.8 a	11.8 a	0.827 a
Picea rubens	1071.0 bc	81.3 b	7.4 ab	9.1 a	11.3 bc	0.834 a
Pinus strobus	917.1 cd	68.8 c	5.7 cd	8.4 ab	12.2 a	0.825 a
Pinus banksiana	1093.9 b	76.6 bc	6.3 bc	8.2 ab	11.6 ab	0.833 a
Pinus resinosa	785.2 de	56.2 d	4.7 de	8.3 ab	11.3 bc	0.826 a
Thuja plicata	652.7 ef	48.7 de	3.7 ef	7.4 bc	10.8 c	0.835 a
Chamaecyparis nootkatensis	1113.2 b	77.3 bc	7.0 bc	9.0 a	11.7 ab	0.830 a
Thuja occidentalis	687.8 ef	47.5 de	3.4 ef	6.9 c	11.5 abc	0.830 a
+ Control	757.0 ef	51.1 de	4.7 de	9.0 a	11.3 bc	0.828 a
- Control	620.8 f	43.8 e	3.2 f	7.1 c	10.7 c	0.828 a
LSD	155.2	12.2	1.3	1.1	0.8	0.011
Trial 2						
% *Abies balsamea* : % *Picea glauca*						
100:0	455.5 ab	23.3 ab	1.8 bc	7.8 ab	8.1 a	0.841 abc
80:20	504.6 a	26.5 a	2.2 a	8.4 a	8.0 a	0.837 cd
60:40	474.2 ab	24.4 ab	2.2 ab	8.8 a	8.0 a	0.842 ab
40:60	494.4 a	25.3 ab	2.1 ab	8.2 a	8.1 a	0.841 abc
20:80	493.4 a	25.0 ab	2.2 a	8.5 a	8.2 a	0.838 abc
0:100	508.2 a	25.8 ab	2.1 ab	8.2 a	8.1 a	0.835 d
+ Control	512.6 a	25.7 ab	2.0 ab	7.8 ab	8.5 a	0.841 abc
- Control	426.0 b	22.4 b	1.6 c	6.9 b	8.0 a	0.845 a
LSD	67.4	3.7	0.4	1.2	0.8	0.026

Treatments followed by the same letter are not significantly different at P=0.05 using a protected LSD test.

Table 2. Effects of sawdust substrates on pepper growth parameters after 5 weeks of treatment.

	Leaf area (cm^2)	Shoot biomass (g FW)	Shoot biomass (g DW)	%DW	Leaf number	FV/FM
Trial 1						
Picea mariana	1017.7 a	55.7 a	4.6 b	8.3 ab	33.7 a	0.790 abc
Picea rubens	735.0 b	42.5 b	3.3 cd	7.8 bcd	29.2 cd	0.776 c
Pinus strobus	676.4 bc	39.8 bc	3.0 d	7.5 cde	29.9 bc	0.792 ab
Pinus banksiana	712.0 bc	40.4 bc	3.0 d	7.4 def	28.9 cd	0.787 abc
Pinus resinosa	638.8 c	35.2 de	2.6 e	7.2 ef	27.1 cd	0.788 abc
Thuja plicata	547.1 d	32.3 e	2.4 e	7.3 def	26.1 d	0.794 ab
Chamaecyparis nootkatensis	758.6 b	42.7 b	3.7 c	8.6 a	28.7 cd	0.796 ab
Thuja occidentalis	644.6 c	34.6 de	2.4 e	6.9 f	29.1 cd	0.794 ab
+ Control	1072.3 a	59.4 a	5.1 a	8.6 a	33.3 ab	0.783 bc
- Control	640.3 c	38.0 cd	3.1 d	8.0 bc	26.9 cd	0.800 a
LSD	85.4	3.8	0.4	0.5	3.5	0.014
Trial 2						
% *Abies balsamea* : % *Picea glauca*						
100:0	569.9 ab	28.6 ab	3.3 a	11.5 a	34.0 a	0.792 bc
80:20	583.8 ab	29.2 a	3.3 a	11.5 a	31.9 ab	0.799 abc
60:40	557.3 ab	28.8 ab	3.2 ab	11.2 a	30.5 ab	0.788 c
40:60	581.3 ab	29.9 a	3.3 a	11.1 ab	33.4 a	0.796 abc
20:80	606.1 a	30.4 a	3.5 a	11.5 a	32.1 ab	0.795 abc
0:100	564.8 ab	27.7 abc	3.1 ab	11.1 ab	29.3 b	0.790 bc
+ Control	508.5 b	24.3 bc	2.6 bc	10.9 ab	31.9 ab	0.802 ab
- Control	511.5 b	23.9 c	2.3 c	10.0 b	30.1 ab	0.808 a
LSD	76.2	4.5	0.6	1.1	4.0	0.013

Treatments followed by the same letter are not significantly different at P=0.05 using a protected LSD test.

Table 3. Effects of sawdust substrates on cucumber growth parameters after 5 weeks of treatment.

	Leaf area (cm^2)	Shoot biomass (g FW)	Shoot biomass (g DW)	%DW	Leaf number	FV/FM
Trial 1						
Picea mariana	189.9 a	62.0 ab	3.8 a	6.1 a	7.9 ab	0.783 b
Picea rubens	882.9 bc	49.6 c	2.8 b	5.5ab	6.7 cd	0.814 a
Pinus strobus	803.9 bc	44.5 cde	2.4 bcd	5.4ab	6.5 cd	0.809 ab
Pinus banksiana	949.3 b	52.2 bc	2.6 bc	5.0ab	6.9 bcd	0.793 ab
Pinus resinosa	689.0 cd	38.4 de	1.9 cd	4.9ab	6.1 d	0.812 ab
Thuja plicata	600.8 d	34.6 e	1.7 d	4.7ab	6.5 cd	0.810 ab
Chamaecyparis nootkatensis	1187.1 a	62.1 ab	3.7 a	5.9ab	7.3 abc	0.791 ab
Thuja occidentalis	848.8 bc	44.9 cd	2.4 bcd	5.3ab	6.7 cd	0.807 ab
+ Control	1318.8 a	88.0 a	4.1 a	6.1 a	8.1 a	0.782 b
- Control	631.7 d	35.9 de	2.1 bcd	6.1 a	6.5 cd	0.810 ab
LSD	208.9	10.1	1.3	1.2	1.1	0.030
Trial 2						
% *Abies balsamea* :						
% *Picea glauca*						
100:0	810.9 bcd	37.5 abc	3.1 b	8.4 a	7.5 cd	0.752 ab
80:20	920.6 ab	41.9 ab	3.9 a	9.4 a	8.3 abc	0.726 b
60:40	967.6 a	43.6 a	3.9 a	9.0 a	8.4 ab	0.747 ab
40:60	892.2 abcd	39.9 abc	3.7 a	9.4 a	8.5 a	0.754 a
20:80	898.8 abc	41.5 ab	3.7 a	8.9 a	8.5 a	0.751 ab
0:100	888.8 abcd	41.1 abc	3.9 a	9.8 a	8.5 a	0.743 ab
+ Control	753.8 d	34.5 bc	3.1 b	9.2 a	7.7 bcd	0.729 ab
- Control	756.7 d	33.6 c	2.8 b	8.8 a	7.3 d	0.746 ab
LSD	138.2	7.6	0.4	1.8	0.8	0.026

Treatments followed by the same letter are not significantly different at P=0.05 using a protected LSD test.