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Interspecific Differences in Postharvest Quality on Mexican Christmas Trees

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Abstract

There are no comparative studies in postharvest quality of Mexican Christmas trees. The objective of this study was to identify the best postharvest performing Mexican cultivated species. The experiment was done in the 2004-2005 season with six replications (trees) of *Abies religiosa*, *Cupressus lindleyi*, *Pinus ayacahuite*, and *Pseudotsuga menziesii*; from two provenances (Tlaxcala and Veracruz) for the last two species. Cultural management was similar. Each tree was placed under dry conditions according to a completely randomized design. Secondary branches, twig diameter and density, initial and final weight, biomass allocation, areas and volumes, total and twig moisture content, foliage density, color, chlorophyll a/b ratio, CO_2 and ethylene production were evaluated. Analyses of variance, comparisons of means, correlation, and simple regression were performed. The four studied species displayed undesirable characteristics. Genetic improvement is required.

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P. menziesii showed values nearer ideotype breeding in more variables. The best provenance was Tlaxcala. Several correlations between variables showed trade-offs in selecting the best species.

Key words: Species testing, postharvest quality, Christmas tree, *Abies religiosa*, *Pinus ayacahuite*, *Cupressus lindleyi*, *Pseudotsuga menziesii*, Mexico.

Introduction

Mexico consumes 1.7 million Christmas trees per year; especially from species of the *Cupressus*, *Pinus*, *Pseudotsuga* and *Abies* genera (SEMARNAT, 2003). There are more than 200 Mexican producers of Christmas trees (CONAFOR, 2003). Christmas tree production generates employment during their cultivation and the holiday season. Land areas used for Christmas tree plantations cannot be used for other purposes due to high steep slopes. Mexican plantations of Christmas trees use native species, allowing preservation of natural forest and associated species' genetic resources. It is the most profitable forest activity[5]. Prices of Christmas trees are higher in Mexico than in USA and Canada; for example, in December of 2003, the price of a 1.80 m *P. menziesii* tree was $US 35 to 45 in Mexico and $US 12 to 15 in USA.

Mexico imports more than 300,000 Christmas trees annually from USA and Canada (SEMARNAT, 2003). Consumers also argue that Mexican trees show lower quality (less postharvest life, yellowing, wilting, abscission, morphology, and so on).

Christmas tree species have different water retention (CHASTAGNER and RILEY, 2003), postharvest drying (SEILER *et al.,* 1988; HINESLEY and SNELLING, 1995, 1997), flammability (WHITE *et al.,* 1997), hydric stage (CHASTAGNER, 1986; CHASTAGNER and HINESLEY, 2002), storage time, leaf color, needle loss, drying time, water absorption, stem wilting (CHASTAGNER, 2002), density (USDA, 2002), aroma loss, and branch flexibility (HINESLEY, 1984). Although there is a considerable amount of information on postharvest characteristics of some species, information from others species is required (BATES, 2002).

Postharvest evaluations have been conducted in species of *Abies* (14), *Pinus* (5), *Picea* (3), *Chamaecyparis* (1), X*Cupressocyparis* (1), *Cupressus* (1), *Juniperus* (1), and *Pseudotsuga* (1) genera (CHASTAGNER, 1986, 2002; CHASTAGNER and HINESLEY, 2002; CHASTAGNER and RILEY, 2003; ELIZALDE, 1979; HINESLEY, 1984; HINESLEY and CHASTAGNER, 2002; HINESLEY and SNELLING, 1991, 1995, 1997; MITCHAM *et al.,* 1988; MONTANO and PROEBSTING, 1985; SEILER *et al.,* 1988). But, there are no studies in several Mexican species.

The objective of this paper was to identify the species with better postharvest quality, among *Abies religiosa*, *Cupressus lindleyi*, *Pinus ayacahuite* and *Pseudotsuga menziesii*; which are cultivated as Christmas trees in Mexico.

[5]) JORGE TORRES PÉREZ, com. pers., 2005.

Materials and Methods

Trees used in this study were harvested in the same day in Christmas tree plantations planted in 1994 (*A. religiosa*, *P. menziesii*), 1995 (*P. ayacahuite*) and 1996 (*C. lindleyi*) and had a similar cultural handling up to harvest. Field packed trees were transported to The Laboratory of Floriculture (*Universidad Autónoma Chapingo*). The experiment was conducted between November 2004 and March 2005.

Trees (between 1.5 and 1.8 m tall) were placed in stands (50 x 50 cm dry wood-support). Laboratory environmental conditions were: 16.5 ± 4.5 °C, 60 ± 25% HR and 11.5 ± 0.5 hours of natural light (20 µmol m^{-2} s^{-1}); during 85 d.

Trees from two provenances were evaluated. a) Tlaxcala (T) is located at 19° 27' N latitude and 97° 55' W longitude; sub-humid and semi-cold climate with summer rain; warmest months: April and May; mean annual precipitation: 1141 mm; temporary streams; protected slopes from strong winds; usually deep soils (Mexico, 2005). b) Vercacruz (V) is at 20° 32' N latitude and 98° 29' W longitude; very rough topography; humid and semi-cold climate, summer rain; mean annual precipitation: 1380 mm (DOMÍNGUEZ, 1986).

The experimental unit was a tree; and six replications were used. The 36 experimental units were arranged in a completely randomized design (six rows and six columns in laboratory). The six treatments (taxa and provenances) were: *A. religiosa* (ArV) and *C. lindleyi* (ClV) from Veracruz, *P. ayacahuite* var. *veitchii* from Tlaxcala (PaT) and Veracruz (PaV), *P. menziesii* var. *glauca* from Tlaxcala (PmT) and Veracruz (PmV).

Trunk diameter was taken at 1.5 m height (from the top to the base) with diameter tape. Trunk area (T_A) was calculated with the formula $T_A = \Pi r^2$. Trunk volume (KV) (from the top to 1.5 m) was calculated using the formula $K_V = 1.5T_A$. Largest (D) and smallest canopy diameters (d) at 1.5 m (from the top to the base) were determined with measure tape TOOL0007 (SUNSCOPE®). Basal area (B_A) was calculated as: $B_A = \Pi[(D + d)/4]^2$. Tree volume (T_V) (from the top to 1.5 m) was calculated as $T_V = 1.5B_A/3$.

Total initial weight (stand included) (TIW) a day after cutting (abbreviated as dac) was determined using a mechanical balance (TORINO®). Stand (SW), total final (stand included) (TFW), trunk (TW) and secondary stem weights (SSW) were quantified (85 dac) with the balance. Abscissed leaves and twig weight (ALTW) were measured with an electronic balance (Scout II, OHAUS®). Intact final twig weight was determined (85 dac) with an electronic balance (Explorer Pro, OHAUS®); after three weeks in an oven (95 °C) (FELISA®), the final dry weight of twigs was evaluated. Initial tree (TIW = TIW-SW), final tree (FTW = TFW + ALTW-SW) and not abscissed leaves and twigs weights (NALTW = FTW-TW-SSW) were also determined. Relative weights were calculated based on FTW.

Foliage density (area) (m^{-1}) was evaluated using a plant canopy analyzer (LAI-2000) with a 45° view cap. Lightness, chroma, and hue were evaluated in young

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(< 50% of maximum length) and mature marked leaves at 3, 10, 17, 30, 47, 66 and 81 dac with a portable sphere spectrophotometer SP62 (X-RITE®). Changes considering the initial data (3 dac) were calculated. Days to maximum change were registered.

Diameter (D, mm) and volume (V, mm^3) of twigs were determined with a caliper and by the water displacement method with a 500 mL graduated cylinder. Twig density (85 dac) ($kg \cdot dm^{-3}$) was calculated by dividing weight by volume.

Young and mature leaves were collected (0.8 g ± 0.2 g) (Explorer Pro, OHAUS®) at 4, 11, 18, 34, 48, 60, and 85 dac. Chlorophyll was extracted according to WITHAM *et al.* (1971); 1:10 [sample: 80% (v/v) cold acetone] the material was grounded with tissue homogenizer T25 B51 (IKA WORKS®) and centrifuged (1600 g, 15 min) with an ultracentrifuge RC-5B (SORVALL®). Absorbance with spectrophotometer Spectronic 21D (MILTON ROY®) was evaluated. Chlorophyll concentration ($mg \cdot g^{-1}$ of tissue) was calculated: Chlorophyll_a = [(12.25 * Absorbance645) – (2.79 * Absorbance663)] * (D/1000W); Chlorophyll_b = [(21.5 * Absorbance663) – (5.1 * Absorbance645)] * (D / 1000W); where W: weight (g) and D: Dilution (110 or 160) (LICHTENTHALER, 1987). Chlorophyll a/b ratio and days to maximum chlorophyll a/b ratio were also determined.

Two approximately 10 g twig samples (young and mature) (electronic balance, Scout II, OHAUS®) of each tree at 4, 11, 18, 34, 48, 60, and 85 dac were collected. Each twig sample was kept in a 50 mL hermetic plastic container with a rubber hose. A day later, a 10 mL air sample was collected and put into a vacuum tube (Vacutainer®). Ethylene and CO_2 concentrations were measured (percentage) with a gas chromatograph Hewlett 5840 Packard Series II. The CO_2 production was evaluated as follows: CO_2 ($mLKg^{-1}h^{-1}$) = %CO2/1,000 * V/W * 1/T; where V: volume of empty space (mL), W: weight (kg), and T: time in hours. The calculation of ethylene production was according to the formula: Ethylene production ($\mu L \cdot Kg^{-1} \cdot h^{-1}$) = % Ethylene/10,000 * V/W * 1/T. For both gases, days to maximum production were determined.

Tree water loss (TWL) (85 dac) was calculated with the formulae: TWL (Kg) = TIW – TFW, and TWL (%) = (TIW – TFW)/ TIW. Approximately 10 g of twig (per tree) were collected 85 dac (electronic balance, Scout II, OHAUS®); this twig was: a) hydrated during 24 hours; b) dripped (excess humidity was eliminated with absorbent paper), c) weighed; d) dried (twig was put into an oven (FELISA®) during two weeks), and e) weighed again. Twig moisture content was calculated with the formula: H (%) = [(Wet weight – Dry weight)/Dry weight] 100.

One way analyses of variance with six treatments (four taxa and two provenances) and six replications per treatment were performed. Relative data were transformed (square root) (prior to analysis of variance) and when many data were zero, 0.01 was added (prior to transformation). Comparison of averages was made using Fisher Least Significant Difference (LSD). Multiple correlations were calculated using Excel®. When a correlation was significant (P = 0.01) a simple linear regression analysis was made (Excel).

Results and Discussion

There were statistical differences among taxa averages for most studied variables (ANOVA, P < 0.05). *P. menziesii* showed data closer to the tree ideotype in more variables (*Figs. 1–7*, *Table 1*). The smallest "trunk volume" was displayed by PmV, whereas the minor "initial weight/volume" corresponded to PmT (LSD, P ≤ 0.05) (*Table 1*). Smaller cut-tree weight reduces transport cost.

C. lindleyi was the only species with cones (LSD, P ≤ 0.05). Precocious reproduction would help a forest breeding program. A short breeding cycle species (eight years) could allow a faster selection program. In addition, *C. lindleyi* cones are small (less than 5 cm diameter) and spread along all tree, so that consumers may not consider them a bad characteristic. In Mexico *C. lindleyi* Christmas trees with cones are actually sold.

Biomass allocation

The best biomass allocation was shown by *C. lindleyi*, with the lowest percentage of trunk and secondary stems (30%), and twigs and leaves with the highest weight percentage (70%) (LSD, P ≤ 0.05) (*Fig. 1*). Bio-

Table 1. – Comparison≠ of means of 13 variables of four species with two provenances^Π.

Variable	ArV	ClV	PaV	PaT	PmV	PmT
Trunk volume (dm^3)	1.39b	1.01b	1.20b	3.06c	0.34a	1.41b
Tree volume (m^3)	0.37c	0.41c	0.56b	0.61b	0.40c	0.69a
Weigh / Volume (Kg/m^3)	28.5d	26.7cd	19.6b	19.3b	25.5c	15.5a
Foliage density (m^{-1})	4.33cd	10.34a	6.37c	4.12d	5.97cd	8.22b
Twig diameter (mm)	3.50b	4.28cd	4.76d	4.25c	2.62a	3.32ab
Twig density (Kg/dm^3)	0.55c	0.56c	0.67d	0.45b	0.35a	0.32a
Moisture loss (%)	63.4bc	68.3c	53.4b	30.8a	89.0d	67.4c
Hue Y (Grade)	109bc	101d	110b	109bc	114a	106c
Lightness Y (%)	48c	55a	50c	44d	53b	56a
Chroma Y (Grade)	17b	5c	25a	25a	16b	18b
Hue M (Grade)	116b	114c	116b	117b	117b	129a
Lightness M (%)	38b	44a	35c	36bc	43a	42a
Chroma M (Grade)	11b	11b	17a	16a	11b	7c

≠ Means, in row, with same letter are not statistically different (LSD, P = 0.05).

Π *Abies religiosa* (Ar), *Cupressus lindleyi* (Cl), *Pinus ayacahuite* (Pa), *Pseudotsuga menziesii* (Pm). Provenances: Veracruz (V), Tlaxcala (T). M: Mature leaf, Y: Young leaf.

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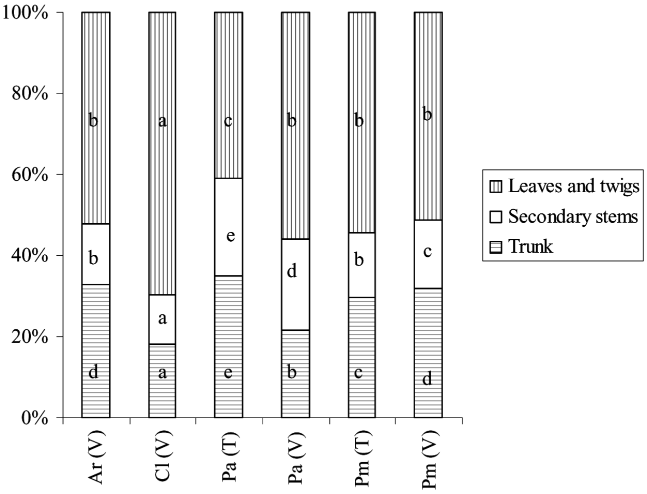

Figure 1. – Biomass allocation (85 days). Means, in column, with same letter show no statistical differences (LSD, P = 0.05). *Abies religiosa* (Ar), *Cupressus lindleyi* (Cl), *Pinus ayacahuite* (Pa), *Pseudotsuga menziesii* (Pm). Provenances: Veracruz (V), Tlaxcala (T).

mass allocation is important for aesthetics and trash handling, since a Christmas cut-tree with light stem and branches is easier to compost.

Foliage

The highest "foliage density" was showed by ClV, the smallest "twig diameter" by PmV, and the lowest "twig density" by PmT and PmV (LSD, $P \leq 0.05$) (*Table 1*). An ideal Christmas tree must have a great biomass dedicated to leaves. The foliage density is an important attribute in postharvest evaluation of cut Christmas trees for aesthetic reasons (USDA, 2002).

The lowest "leaf and twig abscission" corresponded to ArV. ClV showed the highest "leaf and twig abscission" (0.05 Kg), because its dry twigs are fragile and are easily shed; whereas in the remaining species mainly leaves are shed (LSD, $p < 0.05$) (*Fig. 2*). Christmas tree species have shown different degree of leaf abscission (HINESLEY, 1984; CHASTAGNER, 2002).

The Tlaxcala provenance showed the lowest "leaf and twig abscission". Due to lower precipitation and larger evaporation (SICLIM, 1990), this population probably has developed local drought tolerance adaptations,

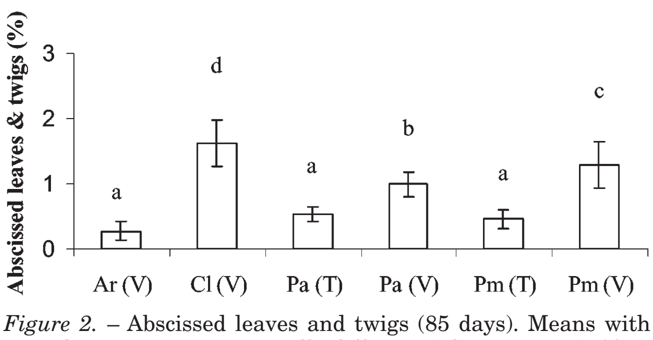

Figure 2. – Abscissed leaves and twigs (85 days). Means with same letter are not statistically different (LSD, P = 0.05). *Abies religiosa* (Ar), *Cupressus lindleyi* (Cl), *Pinus ayacahuite* (Pa), *Pseudotsuga menziesii* (Pm). Provenances: Veracruz (V), Tlaxcala (T).

which is advantageous in postharvest handling. In *Abies concolor*, seed source influences needle retention (BATES *et al.,* 2004), which suggests that leaf retention is a highly hereditary characteristic (HINESLEY and SNELLING, 1997; PARKER and PALLARDY, 1985; NIELSEN and CHASTAGNER, 2005). Twig and leaf retention is a character which could be genetically improved to generate more desirable Christmas trees in terms of house cleaning.

Water loss

The lowest "cut-tree water loss" and "twig water loss" were observed in PaT (85 dac) (LSD, $P \leq 0.05$) (*Table 1*). Christmas tree species have differential capacity to retain water (CHASTAGNER and RILEY, 2003). Cut Christmas tree freshness is a strong function of foliage moisture content (HINESLEY, 1984; CHASTAGNER, 1986; CHASTAGNER and HINESLEY, 2002). Species vary in drying rate after they are cut (SEILER *et al.,* 1988); for example, *Abies fraseri* dried slowly and had long postharvest life (HINESLEY and SNELLING, 1995); however, in this study, *A. religiosa* lost water quickly. In addition, a dry cut-tree surrounded by electrical cable is an *ad hoc* fuel to initiate fire. A dry Christmas cut-tree can be consumed by the fire in less than 30 s (RFD, 2000).

P. menziesii did not show leaf or twig epinasty. The longest "period for downward bending of leaf" was observed in *C. lindleyi* (>85 days); followed by *P. ayacahuite* (15 days), and the worst one was *A. religiosa* (6 days); no differences could be observed between provenances (LSD, $P \leq 0.05$).

Color

Christmas tree ideotype shoud include: a) long period with constant color values, b) great lightness values (60-80%) are preferred, because consumers chosen luminosity trees than dark trees, c) leaves with high hue values (108–130 grades) are prefered (meaning greener leaves), in opposition, low hue values (95–108 grades) means yellower leaves; and d) high chroma values (10–25°) are prefered, because means colorful leaves, in opposition, low chroma values (1–10°) means pale leaves.

Taxa with greater number of favorable color characteristics were ClV (9 variables), PaV and PmT (8 variables). PmT displayed more variables with desirable values compared to the initial color (3 variables). The taxa with more favorable characteristics for young leaves were ClV and PaV (5 variables), and ClV, PaV and PmT for mature leaves (*Table 1*). It is recognized that foliage color is an important variable in postharvest Christmas trees (HINESLEY, 1984; CHASTAGNER, 2002). Foliage color varies between *P. menziesii* populations; green for boreal populations and glaucous for austral ones (DOMÍNGUEZ, 1986; HERMANN and LAVENDER, 1990). But a meticulous research on this particular matter has not been reported. In this work we detected differences in color components among populations and species.

Taxa that presented more favorable characteristics for hue were ClV, PaV, PmT and PmV (two variables). Taxa that showed more favorable characteristics for chroma were PaT and PaV (four variables). Taxa ClV and PmT

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showed greater number of characteristics with better values for lightness (four favorable variables). (*Table 1*).

Chlorophyll, CO_2, and ethylene

In all taxa, "chlorophyll a/b ratio" was constant during 50 days, which can be explained because trunk and branches are important reserves. Thereafter, it was different and the greatest value corresponded to PmV and the worst one to ClV. The "maximum ratio change" was for PmV and the best for ClV. The longest "period for maximum ratio change" was for PaV and the worst one was for PaT (LSD, $P \leq 0.05$) (*Fig. 3a*).

The lowest average in "CO_2 production" was shown by PmV and the worst by ClV. PmV produced the highest amount of CO_2 and ClV the lowest. The largest "period for maximum CO_2 production" was displayed by PaV; and the worst one by PaT (LSD, $P \leq 0.05$) (*Fig. 3b*). Similar data for CO_2 production have been obtained in *P. menziesii* mature trees (MCDOWELL, 2005). A low respiration rate is important because a cut-tree produces a low amount of metabolites.

The lowest average in "ethylene production" was displayed by PmV and the highest one by ClV. The "maximum ethylene production" was observed in PmV and the lowest one by ClV. The largest "period to maximum ethylene production" was shown by PaV and the shortest one by PaT (LSD, $P \leq 0.05$) (*Fig. 3c*). Similar results in ethylene production had been obtained in *Pinus sylvestris* plantlets (IEVINSH and DACE, 1998) and wood (INGEMARSSON *et al.,* 1991). In this research, the maximum values appeared from 48 to 60 dac; previous works, with plantlets, reported maximums between seven and 15 days (IEVINSH and DACE, 1998). In *Citrus* leaves, the precocity of climacteric peak in ethylene production is a function of maturity stage (KATZ *et al.,* 2005). Differences of ethylene production, between cut and uncuted petals, have ben observed (VAN DOORN, 2004).

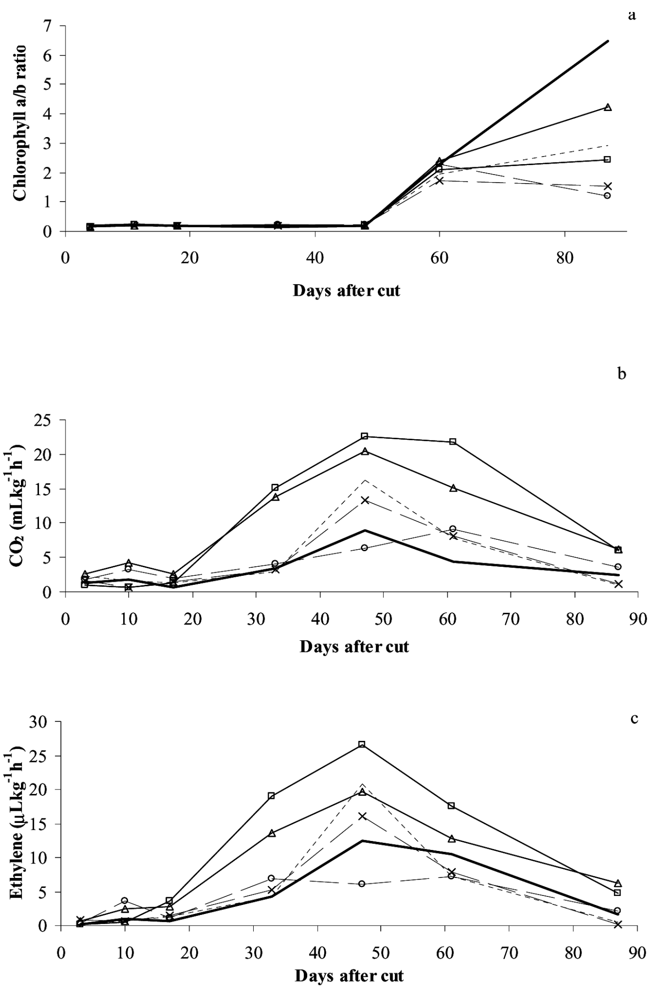

Figure 3. – Dynamics of: a) "chlorophyll a/b ratio", b) "CO_2 production", and c) "ethylene production". ArV. (···), ClV. (—), PaT. (o), PaV. (x), PmT. (□), PmV. (Δ). *Abies religiosa* (Ar), *Cupressus lindleyi* (Cl), *Pinus ayacahuite* (Pa), *Pseudotsuga menziesii* (Pm). Provenances: Veracruz (V), Tlaxcala (T).

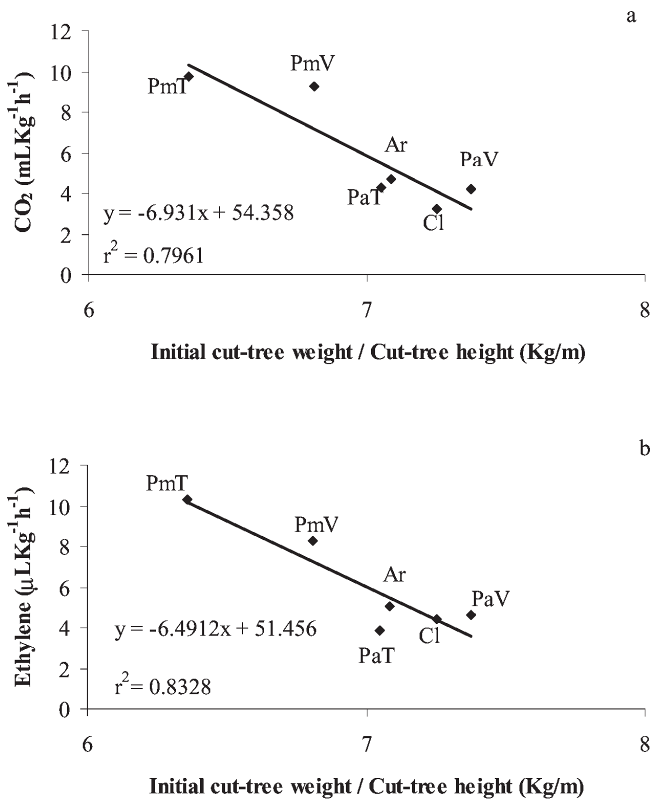

Figure 4. – Means of: a) CO_2 and b) Ethylene production vs initial cut-tree weight (divided by tree-height). *Abies religiosa* (Ar), *Cupressus lindleyi* (Cl), *Pinus ayacahuite* (Pa), *Pseudotsuga menziesii* (Pm). Provenances: Veracruz (V), Tlaxcala (T).

In this research, average "CO_2 production" and "ethylene production" were linearly explained by average "cut-tree initial weight" (divided by "cut-tree height") (*Fig. 4*). In a *Chamaecyparis obtusa* plantation, a logarithmic relationship between weight and respiration was obtained (NINOMIYA and HOZUMI, 1983). These differences, the shape of response curves, can be explained because in the present work we have a lower observation range (cut trees between 1.5 and 1.8 m tall). Also, we contrasted across species and provenances, whereas NINOMIYA and HOZUMI (1983) compared within species.

Weight and volume relationship

"Trunk weight" increases as "trunk volume", "final cut-tree weight" or both increase (*Fig. 5*). Weight and

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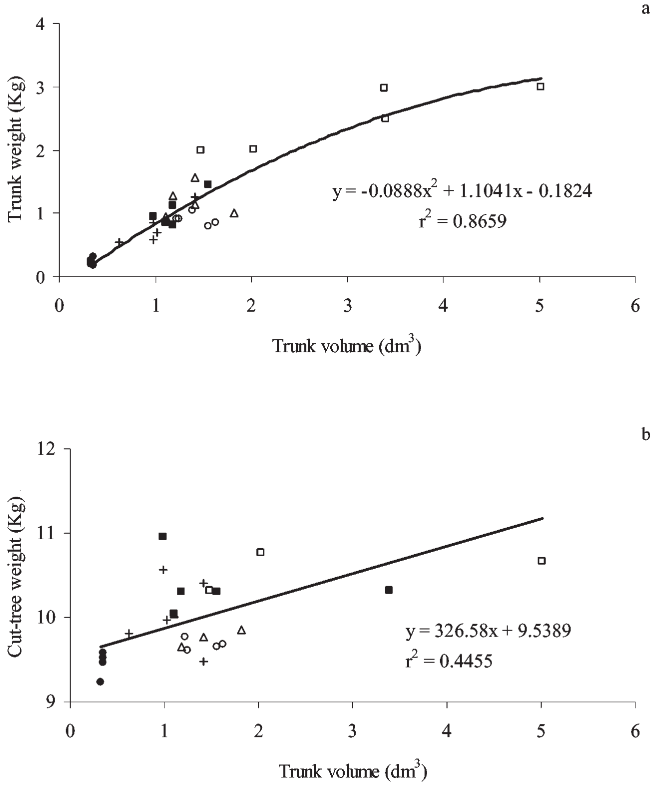

Figure 5. – a) "Trunk weight" vs "trunk volume". b) "Cut-tree weight" vs "Trunk volume". ArV (Δ), ClV (+), PaT (□), PaV (■), PmT (○), PmV (●). *Abies religiosa* (Ar), *Cupressus lindleyi* (Cl), *Pinus ayacahuite* (Pa), *Pseudotsuga menziesii* (Pm). Provenances: Veracruz (V), Tlaxcala (T).

volume trunk relationship has been widely reported in wood production (VANCLAY, 1994), however, it has not been registered for cut Christmas trees.

Provenances

Statistical differences between Tlaxcala and Veracruz provenances were observed in "cut tree weight", "trunk weight", "secondary stem weight", "twig and leaf weight", "twig and leaf abscissed weight"; "trunk volume" and "cut-tree volume"; "initial cut-tree weight/volume"; "foliage densities", "twig densities"; "twig diameter", "loss of tree moisture" and foliage color variables (ANOVA, $P < 0.05$) (*Table 1*) (*Figs. 1–2*).

In Mexico, *P. menziesii* (HERMANN and LAVENDER, 2001), *P. ayacahuite* (PERRY, 1991), *A. religiosa* (AGUIRRE *et al.,* 2000) and *C. lindleyi* are discontinuous populations since they are temperate species that grow at high altitudes (1500–3600 meters over sea level) (PERRY, 1991, FARJON and STYLES, 1997) in this intertropical heavily-mountained country (INEGI, 1985).

Allozymes in *A. religiosa* (AGUIRRE *et al.,* 2000) and *P. menziesii* (PENG and ADAMS, 1989) and microsatellite markers in *P. menziesii* (VIARD *et al.,* 2001) showed low levels of intrapopulation variation and high levels of interpopulation variation. Much of this variation is strongly associated with topographic or geographic characteristics (REHFELDT, 1983). Topoclinal variation in microenvironmental heterogeneity has been reported for *P. menziesii* (HERMANN and LAVANDER, 1990). Seed provenance can have an impact in postharvest characteristics (BATES *et al.,* 2004). Therefore, it is advisable to continue evaluating different Mexican populations from these species to continue identifying provenances with important values in postharvest characteristics.

Desirable relationships

There was a statistically significant linear relationship between "leaf and twig abscission" and "final cut-tree weight" ($p<0.001$). Therefore, these two variables can be jointly selected, because the lightest cut-trees (*A. religiosa* and *P. menziesii* from Tlaxcala) tended to show the lowest leaf and twig abscission. Also, "twig diameter" increases as "trunk weight" decreases; and, in mature leaf, "maximum lightness change" increases as "maximum hue change" increases (*Fig. 6*). "Trunk weight" vs "trunk volume" shows a quadratic relation-

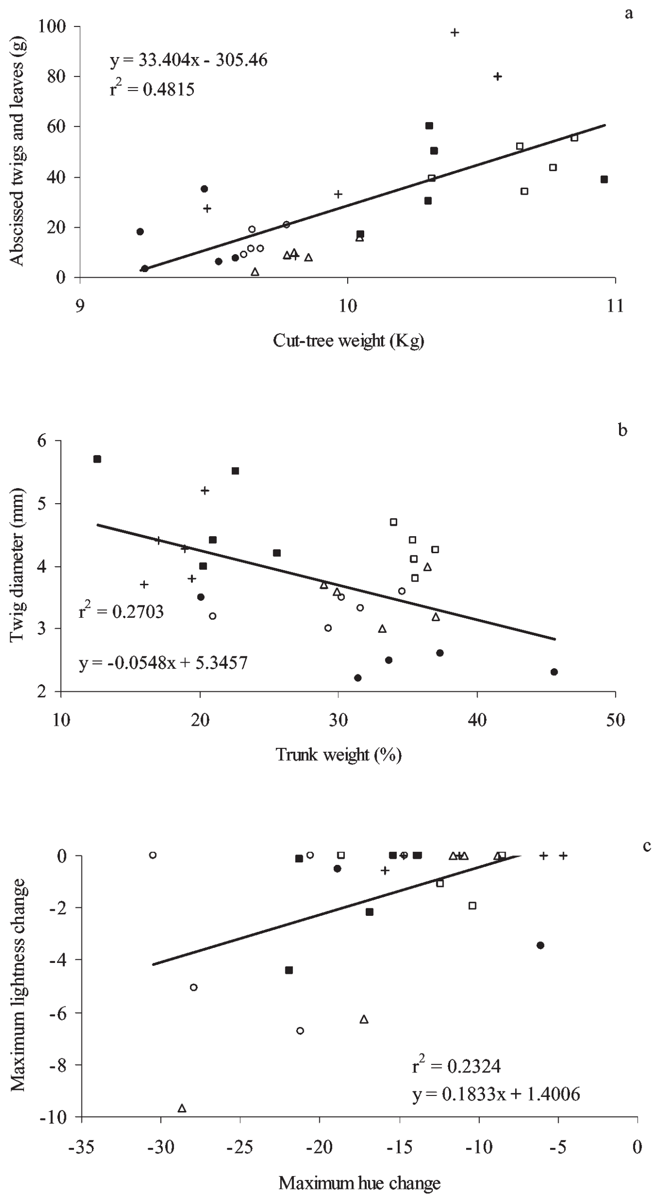

Figure 6. – Desirable relationships. ArV (Δ), ClV (+), PaT (□), PaV (■), PmT (○), PmV (●). *Abies religiosa* (Ar), *Cupressus lindleyi* (Cl), *Pinus ayacahuite* (Pa), *Pseudotsuga menziesii* (Pm). Provenances: Veracruz (V), Tlaxcala (T).

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ship, whereas "Trunk weight" vs "final cut-tree weight" presents a linear relationship (*Fig. 5*). Then, there are some pairs of characteristics with advantages in selection.

Trade-offs

There is a trade-off when two variables are unfavorably related (anthropocentrically speaking). In an analysis of all species, "CO_2 production" and "ethylene production" correlated significantly ($P \leq 0.01$) with "trunk volume" ($r = -0.50$ and $r = -0.56$, respectively) and "trunk weight" ($r = -0.62$, for both cases) ($r \geq$ critical value $= 0.463$). In addition, "trunk weight" explains 75% of the variation in "cut-tree weight" (ANOVA, $P < 0.01$). In this context, the optimal selection constitutes a trade-off, since, if the lightest species is selected (*P. menziesii*) (which implies a reduction in transport costs), at the same time, the species with the fastest metabolism may be selected as well and vice versa (*Fig. 4*). Since this relationship is not perfect, however, there may exist individuals with acceptable values for the two traits.

Other examples of trade-offs are: "moisture loss" decreases when "initial cut-tree weight", "trunk diameter" or both increase; "twig diameter" increases if "final cut-tree weight" increases. In young leaf, "maximum lightness change" increases as "period to maximum lightness change", "maximum chroma change" or both decrease; and, in mature leaf, "maximum lightness change" increases if "maximum chroma change" decreases; in addition, "foliage density" increases when "maximum chroma change in mature leaf" increases, "initial hue in young leaf" decreases or both. Again, although difficult, individuals with a good balance of several traits could be selected. (*Table 2*).

Christmas tree ideotype to look for would be an individual with low trunk percentage and secondary stem weight and high leaf and twig weight percentage. Nevertheless, it might be difficult to select a species with this structure, because "leaf and twig weights" have a significant and positive correlation with "secondary stem weight" ($r = 0.5179$, $P \leq 0.01$). In addition, "secondary stem weight" is significantly and positively correlated with "trunk weight" ($r = 0.8089$, $P \leq 0.01$). If we select a tree species with many twigs and leaves, then we might also indirectly select a species with heavy trunk and secondary branches (*Fig. 7*).

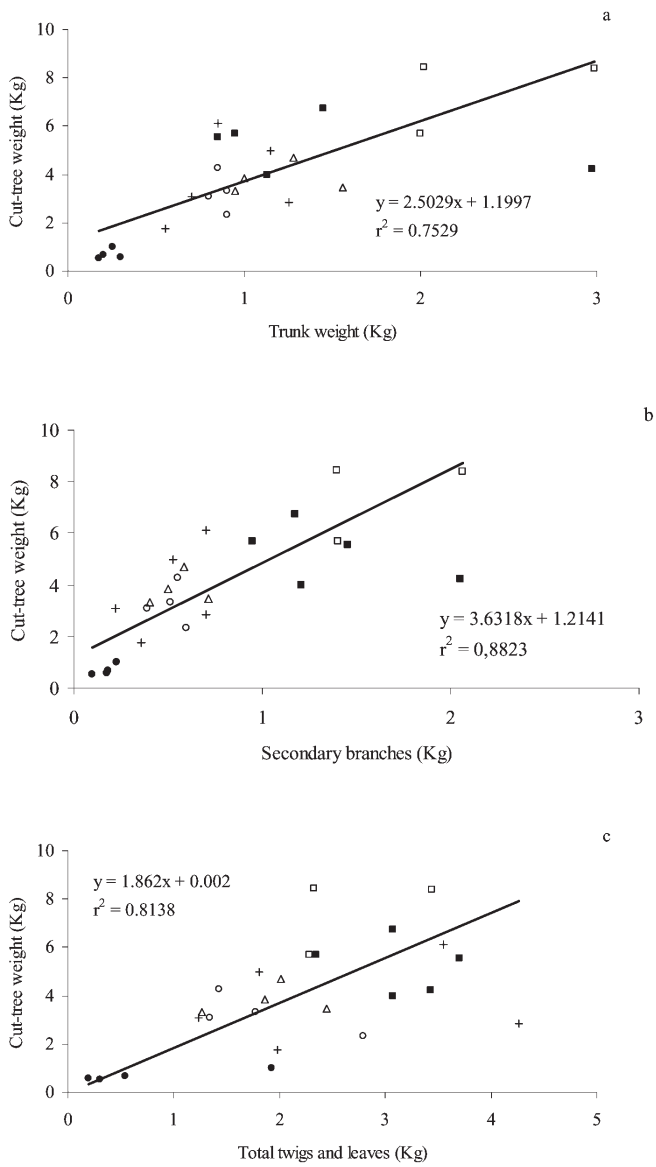

Figure 7. – Trade-offs. ArV (Δ), ClV (+), PaT (□), PaV (■), PmT (○), PmV (●). *Abies religiosa* (Ar), *Cupressus lindleyi* (Cl), *Pinus ayacahuite* (Pa), *Pseudotsuga menziesii* (Pm). Provenances: Veracruz (V), Tlaxcala (T).

Table 2. – Trade-offs. Significative to $0.01 < P \leq 0.05$ (*) and $P \leq 0.01$ (**). Max: maximum, ML: Mature leaf, YL: Young leaf.

Variable y	Variable x	Model	r^2
Moisture loss (%)	Cut tree weight (Kg)	y=389.15 -38.82x	.66**
Moisture loss (%)	Trunk diameter (cm)	y=109.67 -8.75x	.64**
Twig diameter (mm)	Cut tree weight (Kg)	y=-8.49 +1.23x	.48**
Foliage density (m^{-1})	Days to max. lightness change (ML)	y=2.70 +.06x	.35*
Foliage density (m^{-1})	Initial hue (YL) (grade)	y=34.34 -.26x	.27*
Max. lightness change (YL)	Days to max. lightness change (YL)	y=-2.14 -.10x	.37*
Max. lightness change (YL)	Max. chroma change (YL)	y=-9.21 -.27x	.22*
Max. lightness change (ML)	Max. chroma change (ML)	y=-4.22 -.42x	.27*

Trade-offs establish a challenge, because when there is a natural trend (although does not always show a firm definition) the breeder has to look for genetically determined outliers; or an assignation of relative weight to the variables may be necessary through construction of a selection index.

Conclusions

The four studied species displayed undesirable characteristics. Genetic improvement is required. *P. menziesii* showed values nearer ideotype breeding in more variables. The best provenance was Tlaxcala. Several correlations between variables showed trade-offs in selecting the best species.

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Differential Growth and Rooting of Upland and Peatland Black Spruce, *Picea mariana*, in Drained and Flooded Soils

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Abstract

A reciprocal experiment was analyzed to determine whether 30 open-pollinated families of peatland and upland populations of black spruce [*Picea mariana* (Mill.) B.S.P.] sampled from a single area in north-central Alberta, Canada, performed consistently when grown in either flooded or well-drained soils (i.e., if there is a family x soil interaction or generally called genotype x environment interaction (GEI)). The data for the analysis consisted of five traits (height, root dry weight, shoot dry weight, root/shoot dry weight ratio and number of braches) describing growth and rooting performance of tree seedlings in flooded and drained soils (root environments) in a greenhouse for 16 weeks. A mixed-model analysis was used to characterize GEI. The analysis revealed an interesting contrast of GEI patterns between the peatland vs. upland populations: GEI was absent (as indicated by a perfect correlation between flooded and drained soils) in peatland population but present in the upland population. Our results from the characterization of GEI are also consistent with the well-known theory about selection in different environments that correlated responses due to indirect selection are in general less than direct responses. The contrasting patterns of GEI in peatland vs. upland populations may be reflective of different strategies of adaptation to the contrasting environmental conditions, with the peatland trees growing slowly but steadily and with the upland populations growing fast and very responsive to environmental changes.

Key words: Black spruce, genetic correlations, genotype-environment interaction, reciprocal experiment.

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Introduction

The natural range of black spruce [*Picea mariana* (Mill.) B.S.P.] covers most of the Canadian territory. This conifer grows on a variety of topographical conditions, moisture regimes and edaphic types within the Canadian boreal forest (ROWE, 1972; FARRAR, 1995). The range-wide surveys of this species (MORGENSTERN, 1978; BEAULIEU et al., 2004) have showed clinal differentiation, but ecotypic differentiation with respect to peatland and upland conditions in individual locations has not been conclusively demonstrated (MORGENSTERN, 1969; FOWLER and MULLIN, 1977; O'REILLY et al., 1985; WANG and MACDONALD, 1992; YEH et al., 1993).

Within a single site, the growth conditions of black spruce trees vary considerably including water-logged peatlands to well-drained mineral-soils. If soil (root environment) is an important habitat factor in differentiation of upland and peatland black spruce, soil influences should be reflected in characteristics of the rooting system and growth potential as adaptations. Thus, in a reciprocal test, trees grown on the substrate closest to its original habitat type are expected to be superior to the other trees grown on a different substrate in characteristics of rooting system and growth potential. In this regard, the reciprocal experiment would help answer a longstanding question in plant and animal breeding: should selection be conducted in a good environment, giving maximal expression to the desired character, or should it be carried out under the conditions in which the organisms will eventually live and grow? Conceptually the answer to the question depends on the extent to which the trait exhibits interaction between genotypes and environments (GEI). If the rank order and relative magnitudes of phenotypic expression for genotypes affecting the trait are the same across a range of environments, then there is no GEI and it does not matter in which environment the selection is conducted. However, if the expression of the trait changes rank or magnitude among the different genotypes, there is GEI and it

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