Hybrid Vigor in *Larix:* Growth of Intra- and Interspecific Hybrids of *Larix decidua, L. laricina,* and *L. kaempferi* After 5-Years

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Abstract

Fifth-year growth measurements were compared among 25 intraspecific crosses of *Larix decidua* MILL. (E), *L. laricina* (DU ROI) K. KOCH (T), *L. kaempferi* (SIEB. and ZUCC.) GORD. (J), and 27 interspecific hybrid crosses between ExJ, JxE, ExT, TxE, and TxJ, all planted in a progeny test in Johnson Mountain Township, Maine, USA. Heights for intraspecific hybrid families ranged from 2.6 m to 3.8 m, compared with 3.3 m to 4.1 m for interspecific hybrid families. Hybrid vigor is clearly indicated, since 17 of the 20 tallest families in the test were interspecific hybrids. There was no clear superiority overall among the grouped interspecific hybrids of JxE, ExJ, TxE, or ExT. Hybrids between T and J produced very few seed, but these crosses were among the best in the test. By selecting the 5 best hybrid families in the test (4 of 5 were ExJ or JxE hybrids) gains of 37% and 104% in height and volume can be obtained in comparison with 2 commercial check lots of E and ExJ.

Key words: Progeny testing, *Larix decidua, L. laricina, L. kaempferi,* hybrid larch.

FDC: 165.7; 232.13; 561.1; 174.7 *Larix decidua;* 174.7 *Larix laricina;* 174.7 *Larix leptolepis;* (741).

Introduction

Tree breeding programs across North America, Europe, and Asia have included *Larix* for over 80 years (HENRY and FLOOD, 1919). *Larix decidua* MILL. and *Larix kaempferi* (LAMBERT) SARGENT (SIEB and ZUCC) GORD. are common reforestation species in western Europe along with their hybrid, while in the Lake States and Northeast U.S. and Canada *L. decidua, L. kaempferi,* and *L. laricina* (DU ROI) K. KOCH are also used for reforestation. In some cases, tree-breeding programs have been established to develop improved intraspecific seed and interspecific hybrids.

The main reason for planting *Larix* species and hybrids in North America is that they consistently outgrow all other conifers. EINSPAHR *et al.* (1984) reported a growth advantage of 29% for *L. decidua* over *Pinus strobus* L. for total volume at age 19 and 23% growth advantage over *Pinus resinosa* AIT.. *Larix decidua* and *L. kaempferi* outgrew all other species in height, and only *Pinus resinosa* had a higher diameter in 41 to 84 year old plantations (GRISEZ, 1968). Similarly, STIPANICIC (1975) reported that plantations of *L. kaempferi* yielded 348 m^3/ha compared to 185 m^3/ha for *Picea glauca* (MOENCH) VOSS and 178 m^3/ha for *Pinus resinosa* at age 28.

Hybrid vigor or heterosis has been well documented in *Larix decidua* x *kaempferi* (MILLER and THULIN, 1967; CARTER *et al.,* 1981; RIEMENSCHNEIDER and NIENSTAEDT, 1983; EINSPAHR *et al.,* 1984; CARTER and SELIN, 1987; MATYSSEK and SCHULZE, 1987; and PAQUES, 1992). In a trial established in Quebec, *L. decidua* x *kaempferi* hybrids showed a 31% gain in height and 107% gain in total tree volume compared to *L. decidua* at age 5 (VALLEE and STIPANICIC, 1983). However, interspecific hybridization between *L. laricina* and *L. decidua* or *L. kaempferi* has been investigated only on a limited scale (MACGILLIVRAY, 1967; AVROV, 1982; PAQUES, 1992). In a field trial in France, PAQUES (1992) reported on the performance of *L. laricina* x *decidua* and a tri-hybrid between *L. laricina* x (*decidua* x *kaempferi*). MACGILLIVRAY (1967) observed hybrid vigor in four *L. laricina* x *kaempferi* seedlings in New Brunswick. There have been no reports of interspecific hybrids involving *Larix laricina* in the Lake States or Northeast U.S. Although there are numerous provenance studies involving *L. laricina, L. decidua,* and *L. kaempferi,* there have been no studies dealing with variation among control-pollinated full-sib hybrid families. This study is unique in that it involves three species of larch and five interspecific hybrids, including hybrids between *L. laricina* and *L. decidua* or *L. kaempferi,* and that it reports on variations among hybrid families.

The objectives of this study are to: i) compare the height and diameter growth of all intraspecific families and interspecific hybrids between *L. decidua, L. laricina,* and *L. kaempferi,* and ii) quantify family variation within hybrid groups to demonstrate the potential gains for family selection among hybrid groups. Although the superiority of *L. decidua* x *kaempferi* has been well documented, other interspecific hybrids may show equal or superior growth. The *L. decidua* x *kaempferi* hybrid currently used by S.D. Warren Co. represents a single maternal parent, so the opportunity to exploit family variation should be explored.

Materials and Methods

An hybrid larch progeny test was planted in May, 1992, on a well-drained, rocky upland site with a west-facing slope in Johnson Mountain Township, Maine on S.D. Warren Co. land (latitude 45° 30' north, longitude 70° 5'). Before harvesting and planting, red maple and paper birch with a component of red spruce and balsam fir had dominated the area. The test site is adjacent to operational hybrid larch plantations that are being established by S.D. Warren.

The plant material included 10 cm to 25 cm tall seedlings from intraspecific crosses of *Larix decidua* (ExE), *L. laricina* (TxT), *L. kaempferi* (JxJ), and interspecific hybrids between *L. decidua* and *L. kaempferi* (ExJ), *L. decidua* and *L. laricina* (ExT), *L. kaempferi* and *L. decidua* (JxE), *L. laricina* and *L. decidua* (TxE), and *L. laricina* and *L. kaempferi* (TxJ). The maternal parent in each of the above crosses is listed first. All of the breeding was completed in an indoor breeding orchard in November 1991 (EYSTEINSSON *et al.,* 1993). A list of all parents and their origin is shown in *table 1*. A total of 46 full-sib

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families from ExE, JxJ, TxT, ExJ, JxE, and TxE were included in the test. These crosses are listed in *table 7*, and the letters indicate the species identity of the female and male parent, while the numbers identify specific clones. For example, JE63 is a cross between *Larix kaempferi* (clone 6 as female parent) and *Larix decidua* (clone 3 as male parent); EJ36 would be the reciprocal cross. Successful hybridization is generally difficult to obtain between ExT and TxJ (AVROV, 1982; PAQUES, 1992; EYSTEINSSON *et al.,* 1993), so seed from full-sib crosses were pooled to create two half-sib families from TxJ for the test. Thirty individuals, some related and some with no parents in common, make up a "family" from ExT. Three additional seed sources were included in the progeny test to serve as check lots: xLD-LL-7-89, an open-pollinated ExJ hybrid (von Lochow) which was produced in Europe; xLD-4-89, a *L. decidua* seed source from Poland; and a non-select half-sib family of *L. laricina.* Both the ExJ and ExE check lots are planted commercially in Maine by S.D. Warren.

Table 1. – Age, location, and provenance of origin of exotics of trees used as scion doners for larch breeding orchard.

Clone	Age (1987)	Location (Origin)
Larix laricina		
T1	31	Argyle, Maine
T2	49	China, Maine
T3	53	Hampden, Maine
T4	25	LaGrange, Maine
T5	57	Skowhegan, Maine
T6	28	Moscow, Maine
Larix decidua		
E1	28	Iowa (Breslau, Poland)
E2	28	Iowa (Breslau, Poland)
E3	29	Iowa (Wroclaw, Poland)
E4	28	Iowa (Breslau, Poland)
E5	37	Iowa (Pinczow, Poland)
Larix kaempferi		
J1	10	Maine (Central Honshu, Japan)
J2	10	Maine (Nagano Prefecture, Japan)
J3	10	Maine (Kiso-Komagatake, Nagano, Japan)
J4	10	Maine (Yatsugatake, Nagano, Japan)
J5	10	Maine (Otaki, Nagano, Japan)
J6	10	Maine (Sorachi, Japan)

The trees representing each family were planted in 3-tree row plots at a 2.3 m x 2.3 m spacing in 10 replications using a randomized complete block design. A single border row was planted around the entire test. Prior to planting an aerial application of herbicide was applied in September 1991. Trees were released from hardwood sprout competition by a basal application of Garlon® in November 1992.

Measurements

Heights of trees were measured at the end of the 2nd and 3rd growing seasons. Height, diameter at breast height (DBH), and diameter at ground line (GLD) were measured after growth had ceased in 1995 and 1996 (4th and 5th growing seasons, respectively). Ground line diameter was measured at approximately 10 cm above ground in order to obtain an estimate of volume ($1/3\pi r^2 h$) which might show different patterns of variation than for height. Survival was also monitored annually. In order to compare test family performance with that of the operational plantation, 200 trees were randomly selected for measurement in 1996 from an adjacent hybrid larch operational plantation that contains the von Lochow ExJ hybrid. The operational plantation was established at the same time as the progeny test but with 1-0 planting stock. Height and DBH were measured on each of the trees, and mean height and DBH of the operational plantation served as an additional check.

Statistical Methods

After investigation into reasons for lack of normality and unequal error variances, data from 1996 for height and DBH were ranked in order to have normally distributed and sufficiently stabilized error variance. ANOVAs comparing both the hybrid groups (H_i) shown in *table 2* and families overall (F_i) were performed. An analysis of variance was performed on the ranked data for height and DBH using the following model in SYSTAT (1996):

$$Y_{ijk} = \mu + H_i + B_j + (HB)_{ij} + \epsilon_{ijk} \quad [1]$$

where Y_{ijk} is the variable mean of the i^{th} hybrid group in the j^{th} block, μ is a constant, H_i and B_j are the hybrid group and block main effects, respectively, $(HB)_{ij}$ is their interaction, and ϵ_{ijk} is the residual error. Hybrid group as a main effect was tested using the $(HB)_{ij}$ interaction as the error term. BONFERRONI converted t-tests at 5% level were used to compare hybrid means for height and DBH.

A second analysis of variance was performed on height and DBH for the 52 families included in the progeny test using the following model (SAS, 1996):

$$Y_{ij} = \mu + F_i + B_j + \epsilon_{ij} \quad [2]$$

where Y_{ij} is the variable mean of the i^{th} family in the j^{th} block, μ is a constant, F_i and B_j are the family and block main effects, respectively, and the error, ϵ_{ij}, is the $(FB)_{ij}$ interaction. Only

Table 2. – Total number of seedlings planted (n_i), percent survival, mean HT, mean DBH, mean GLD, height increment (HI), and mean volume by hybrid group for 1996. Commercial check means are listed for comparison.

Hybrid Group	n_i	Surv. (%)	HT, m	DBH, cm	GLD, cm	HI, cm	Volume, cm^3
ET	30	87	3.7	3.9	7.4	111	6234
TJ	55	80	3.7	3.6	6.9	103	5268
TE	180	78	3.7	3.8	7.0	106	5724
JE	262	77	3.7	3.9	7.4	106	5937
EJ	240	83	3.6	3.9	7.2	100	5617
TT	300	91	3.4	3.1	6.0	93	3596
EE	210	85	3.4	3.4	6.7	95	4820
JJ	210	67	2.9	2.6	5.7	84	3039
XLD-4-89	30	77	3.3	3.1	6.7	86	4285
XLD-LL-7-89	30	77	2.7	2.4	5.7	92	3107

family as a main effect was tested using the $(FB)_{ij}$ interaction as the error term. Family means for height and DBH were compared using BONFERRONI's adjusted t-test at 5% level. Four-year height trends are also reported.

Results

Hybrid Groups

Species/hybrid group means for all variables measured in 1996 are summarized in *table 2*. Overall survival for the entire progeny test after 5 growing seasons was 81%. Group survival ranged from a low of 67% for *Larix kaempferi* to 91% for *L. laricina*. Interspecific families averaged just under the test mean with 80% survival. The two commercial check lots had a mean survival of 77%.

Highly significant differences for 1996 mean height were detected by ANOVA model (1) among groups, blocks, and their interaction (*Table 3a*). The progeny test mean height in 1996 was 3.4 m and ranged from 2.9 m for *L. kaempferi* to approximately 3.7 m for the interspecific hybrids (*Table 2*). Interspecific hybrid groups exhibited little variation in their mean height, and BONFERRONI's test revealed that their mean heights were not statistically different from one another. However, interspecific hybrid groups ExJ, JxE, and TxE had significantly larger mean heights after five growing seasons than did intraspecific crosses among *L. decidua, L. laricina,* and *L. kaempferi,* with the latter exhibiting the lowest mean height of all groups in the test (*Table 4*). The height of the von Lochow commercial check was significantly lower in 1996 than the mean height of any of the hybrid groups in the progeny test. Although the mean DBH of the operational plantation was not below the progeny test mean, the operational plantation had a mean height of 3.32 m, which was below the mean height for the progeny test. Hybrid heights in blocks 9 and 10 were significantly lower than heights in blocks 1 to 8.

Table 3. – Analyses of variance for hybrid group HT and DBH after 5 years based on model 1 (a) and model 2 (b).

(a)		Height		DBH	
Source	DF	F-Ratio	P	F-Ratio	P
Hybrid	7	28.52	0.0000	20.32	0.0000
Block	9	16.66	0.0000	12.57	0.0000
Bl x Hyb	63	1.54	0.0050	1.17	0.1703
Error	1171				

(b)		Height			DBH
Source	DF	F-Ratio	P	F-ratio	P
Family	51	8.10	0.0001	4.58	0.0001
Block	9	-----	-----	-----	----
BxF ($\in_{ij}$)	444	1.35	0.0002	1.25	0.0047

Table 4. – Matrix of pairwise comparison probabilities for 1996 height between all hybrid groups and intraspecific crosses (BONFERRONI t-test). An X indicates that mean height is different at a significance level of $p < 0.05$ (DBH comparisons are exactly the same as reported for height).

	JxJ	ExE	TxT
JxJ			
ExE	X		
TxT	X		
ExJ	X	X	X
JxE	X	X	X
TxE	X	X	X
ExT	X		
TxJ	X		

Highly significant differences were also detected by model (1) for DBH among hybrid groups and blocks, but the interaction was not significant (*Table 3a*). Mean DBH for hybrid groups ranged from 2.6 cm for *L. kaempferi* to 3.9 cm for ExT while averaging 3.4 cm (*Table 2*). While DBH for interspecific hybrid groups ExJ, ExT, JxE, and TxE were closely similar, all interspecific hybrid groups had a mean DBH greater than any of the parent species. BONFERRONI multiple comparisons revealed that interspecific hybrids ExJ, JxE, and TxE had statistically larger diameters than any of the parent species, which follows exactly the same results as shown for height (*Table 4*). *Larix kaempferi* had significantly smaller diameters than all other groups ($p < 0.0286$). The *L. decidua* commercial check (xLD-4-89) had a mean DBH smaller than all of the hybrid groups with the exception of JxJ. The von Lochow commercial check (xLD-LL-7-89) had the smallest DBH in the progeny test. The mean DBH based on 200 trees in the operational plantation was 3.6 cm. Trees in blocks 9 and 10 had significantly smaller mean DBH than trees growing in other blocks, while the mean DBH for blocks 1 to 8 were not significantly different from one another.

Ground line diameter (GLD) by group ranged from 5.7 cm for *L. kaempferi* to 7.4 cm for hybrid group ExT (*Table 2*). The progeny test had a mean GLD of 6.7 cm. All interspecific hybrids had a mean GLD greater than their parent species (*Table 2*). As was the case with DBH, the von Lochow commercial check had the smallest mean GLD in the progeny test. Estimates of volume based on GLD and height ranged from 3,039 cm^3 for *L. kaempferi* to 6,234 cm^3 for the *L. decidua* x *laricina* hybrid (*Table 2*).

Family Groups

Highly significant differences in height were also detected using analysis of variance model (2) for family (*Figure 1, Table 3b*). Heights after 5 years ranged from 2.6 m for family JJ61 to 4.1 m for EJ11 (*Table 7*). Mean heights for the three check lots were below the test mean, and were 0.5 m to 1.0 m below the average height for the five tallest families (*Figure 2*). BONFERRONI t-tests revealed that family EJ11 was significantly taller than all three checks, and that families EJ42 and TE43 were significantly taller than the two commercial checks. The von

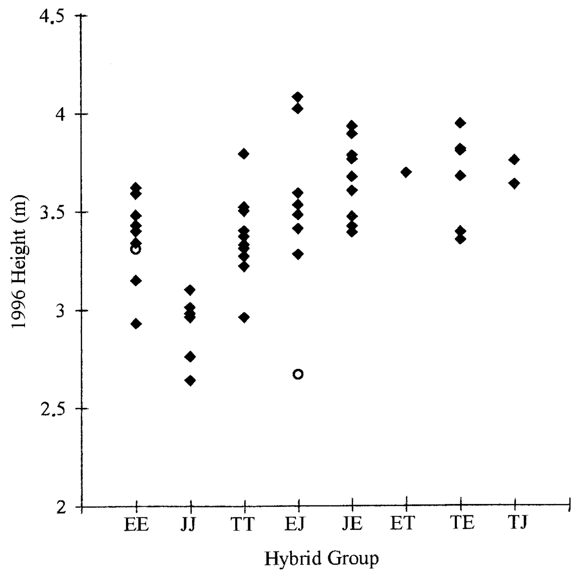

Figure 1. – Variation within hybrid group for 1996 height. Black diamonds represent individual families. Open circles represent commercial check lots.

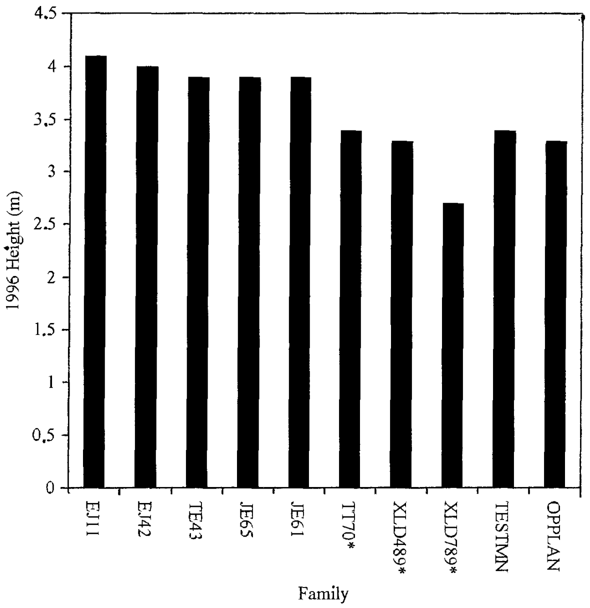

Figure 2. – Comparison of 1996 heights among the top five ranked families for height in the progeny test and the three check lots (*). Also shown are the progeny test mean height and the mean height of the operational plantation.

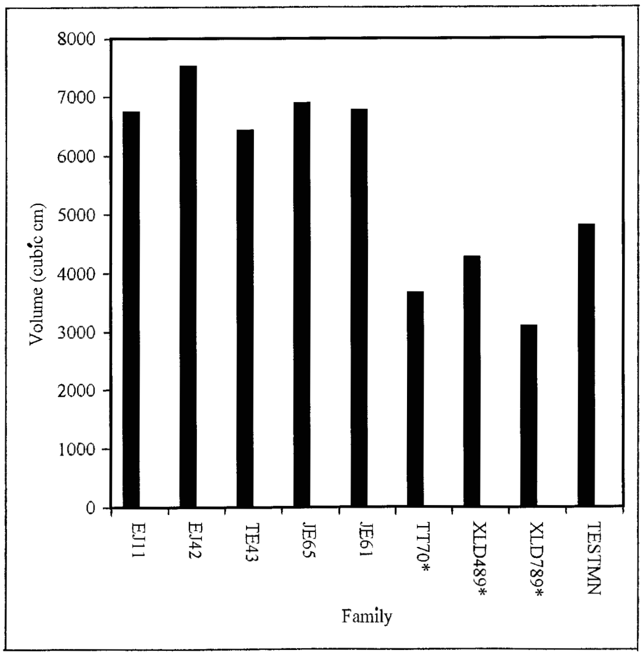

Figure 3. – Comparison of volume estimates among the top five ranked families for height in the progeny test and the three check lots (*). The progeny test mean volume ist also shown.

Lochow check was significantly smaller than the five tallest families in the test, and had the second worst height overall. The mean height of the operational plantation was below the five tallest families and the test mean.

DBH among families was also significantly different, and ranged from 2.3 cm for family JJ63 to 4.4 cm for families JE65 and TE65 in 1996 (*Table 3b*). The three check lots are well below the progeny test mean DBH. DBH for the von Lochow hybrid was the second smallest in the test and was significantly smaller than the DBH of the five tallest families. Although the mean DBH of the operational plantation is slightly higher than the progeny test mean, it is about 0.5 cm smaller than the average of the five tallest families.

Mean GLD ranged from 5.1 cm for family JJ63 to 8.2 cm for family EJ42. The mean GLD of the three check lots was significantly below the five tallest families in the test. The non-select *L. laricina* check and the von Lochow hybrid were below the test mean. Volume estimates for families ranged from 2,419 cm^3 for JJ61 to over 7,500 cm^3 for EJ42 with an overall mean of 4,823 cm^3. Volumes for the five tallest families in the test and check lots are compared in *figure 3*.

Rank changes in height were followed between 1993 and 1996 (*Table 7*). In 1993 fourteen of the 20 bottom ranking families for height were all intraspecific families among *L. decidua, L. laricina,* or *L. kaempferi* (*Figure 4*). In all other years 15 out of the bottom ranking families for height were intraspecific families. All of the JxJ families ranked in the bottom twenty for height between 1994 to 1996. In 1996 both commercial checks ranked in the bottom twenty for height, and the mean height for the von Lochow hybrid was the smallest in years 1993 to 1995 and second smallest in 1996. The ranking of *Larix laricina* families declined sharply between 1994 to 1996 (*Table 7*), while most JxE crosses were improving in rank over time. In five reciprocal crosses involving JxE or ExJ, JxE always did better. In 1993 sixteen out of the 20 tallest families were interspecific hybrids, and this number increased to 17 by 1996. Family EJ42 ranked number one for height in 1993 to 1995 and number two in 1996.

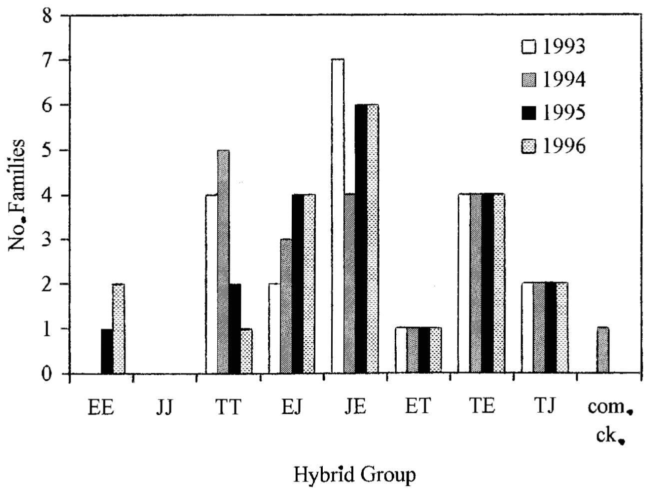

Figure 4. – Number of families ranked in the top twenty for height, 1993 to 1996.

Discussion

Overall survival at the Johnson Mountain Township larch progeny test (81%) compared favorably to those of WEISER (1992), who reported survival of 73% and 74% for 15-year old progeny tests of *Larix decidua,* and 77% for a 20-year old *L. decidua* x *kaempferi* hybrid test. In contrast to the survival of *L. kaempferi* and *L. laricina* reported here, in Europe PAQUES (1992) reported survival rates at age 8 for *L. kaempferi* of nearly 92% and 71% for *L. laricina.* PAQUES (1992) attributed the high mortality of *L. laricina* progenies to provenance origin and severe weather, i.e. windy, conditions of the test site. This was the opposite of what is reported here for survival of *L. kaempferi* and *L. laricina.* The high survival of *Larix laricina* families (91%) in this test was expected since it is a native species and adapted to the area. *Larix kaempferi* is relatively more vulnerable to cold temperatures and exhibited extensive leader die-back which probably accounted for its high mortality and relatively poor growth in this test. FARNSWORTH *et al.* (1972), CARTER *et al.* (1981), and RIEMENSCHNEIDER and NIENSTAEDT (1983) also observed leader dieback during the winter and spring for *L. kaempferi*. ZACZEK *et al.* (1994) also observed poor survival of *Larix kaempferi* after 7 growing seasons at two Pennsylvania sites. However, they attributed the poor survival of the *L. kaempferi* to severe drought.

Interspecific hybrids have been reported to have better survival than either parent. ZACZEK *et al.* (1994) observed that *Larix decidua* x *kaempferi* hybrids had greater survival than *L. kaempferi* especially on poor sites. In a 5-year old test in New Zealand, MILLER and THULIN (1967) reported that *L. decidua* x *kaempferi* hybrids survived better than either *L. decidua* or *L. kaempferi*. In this study, interspecific hybrids survived better than *L. kaempferi*.

Table 5. – Percent gain in height from selecting the five tallest families over the mean of interspecific hybrids, the mean for the three species, and the pooled mean of the two commercial checks (standard error in parentheses).

Family	% over interspecific hybrid mean	% over species mean	% over commercial checks
EJ11	11.9 (2.9)	25.4 (3.3)	36.6 (3.6)
EJ42	10.3 (3.1)	23.6 (3.5)	34.6 (3.8)
TE43	8.2 (4.6)	21.2 (5.1)	32.0 (5.6)
JE65	7.7 (4.0)	20.7 (4.4)	31.5 (4.8)
JE61	6.5 (3.1)	19.4 (3.5)	30.0 (3.8)

Table 6. – Percent gain in volume from selecting the five tallest families over the mean of interspecific hybrids, the mean for the three species, and the pooled mean of the two commercial checks (standard error in parentheses).

Family	% over interspecific hybrid mean	% over species mean	% over commercial checks
EJ11	15.7 (10.5)	75.4 (15.9)	82.9 (16.6)
EJ42	29.1 (11.9)	95.7 (18.0)	104.0 (18.8)
TE43	10.3 (12.9)	67.3 (19.5)	74.4 (20.3)
JE65	18.2 (12.0)	79.2 (18.3)	86.9 (19.0)
JE61	16.2 (9.3)	76.2 (14.0)	83.7 (14.6)

Heights of intraspecific crosses of *Larix decidua, L. laricina,* and *L. kaempferi* were all below the test mean, while heights of interspecific hybrids were above their respective parent species, including interspecific hybrids involving *L. laricina*. PAQUES (1992) reported contrasting results, where *L. laricina* x *kaempferi* hybrid mean height was below both *L. laricina* and *L. kaempferi* through age 8. However, the tri-hybrid *L. laricina* x (*decidua* x *kaempferi*) ranked second in height below *L. decidua* x *kaempferi*. In New Brunswick MACGILLIVRAY (1967) also report that *L. laricina* x *kaempferi* hybrids were 48% and 57% taller than *L. laricina* and *L. kaempferi*, respectively.

The results reported here are in agreement with all previous reports in that *Larix decidua* x *kaempferi* hybrids exhibited relatively fast growth. Six of the top ten families were either *L. decidua* x *kaempferi* or the reciprocal cross, although 3 ExJ and

Table 7. – Four year height trends (rank), 1993 to 1996.

Family	93 HT(cm)	94 HT(cm)	95 HT(cm)	96 HT(cm)
EJ11	99.7 (7)	173.6 (6)	296.2 (2)	408.2 (1)
EJ42	113.4 (1)	203.5 (1)	302.5 (1)	402.3 (2)
TE43	101.3 (6)	176.4 (4)	278.5 (4)	394.5 (3)
JE65	93.3 (19)	163.3 (14)	284.9 (3)	393.0 (4)
JE61	96.1 (14)	160.6 (15)	269.1 (9)	388.6 (5)
TE11	98.7 (9)	166.4 (9)	266.4 (10)	381.5 (6)
TE65	102.3 (5)	180.2 (2)	276.1 (5)	380.4 (7)
TT24	109.8 (2)	179.4 (3)	271.6 (7)	379.5 (8)
JE64	93.7 (18)	159.5 (17)	261.8 (12)	378.2 (9)
JE62	95.8 (15)	154.8 (26)	260.5 (14)	376.4 (10)
TJ50	102.9 (4)	168.2 (7)	275.4 (6)	374.7 (11)
ET00	97.0 (11.5)	159.3 (18.5)	258.2 (19)	369.5 (12)
TE21	86.5 (27)	159.2 (20)	264.9 (11)	367.1 (13)
JE63	80.8 (42)	154.4 (27)	260.2 (16)	366.9 (14)
TJ20	109.2 (3)	168.1 (8)	269.6 (8)	363.5 (15)
EE35	86.4 (28)	159.0 (21)	254.0 (24)	361.8 (16)
JE21	97.0 (11.5)	149.0 (34)	252.5 (25)	360.5 (17)
EJ46	86.2 (29.5)	151.2 (31)	255.8 (21)	359.1 (18.5)
EE13	73.0 (48)	146.4 (37)	255.6 (22)	359.1 (18.5)
EJ36	82.8 (38)	155.2 (25)	252.3 (26)	352.6 (20)
TT46	95.1 (16)	174.5 (5)	261.6 (13)	351.7 (21)
TT61	94.0 (17)	165.5 (10)	255.1 (23)	349.8 (22)
EE34	91.7 (21)	156.7 (23)	255.9 (20)	348.5 (23.5)
EJ31	88.3 (25)	159.6 (16)	259.3 (17)	348.5 (23.5)
JE23	93.1 (20)	156.1 (24)	246.7 (30)	346.7 (25)
TT52	86.2 (29.5)	144.2 (39)	246.3 (31)	343.3 (26)
JE25	98.3 (10)	164.3 (13)	260.4 (15)	342.1 (27)
EJ12	90.0 (22)	146.8 (36)	235.0 (36)	341.0 (28)
TT70	96.5 (13)	165.1 (11)	251.4 (27)	340.4 (29)
EE25	87.3 (26)	149.8 (33)	249.8 (29)	339.9 (30)
JE33	80.9 (41)	144.7 (38)	233.6 (38)	339.4 (31.5)
TE15	99.2 (8)	158.0 (22)	250.6 (28)	339.4 (31.5)
EJ26	88.5 (23.5)	154.3 (28.5)	258.9 (18)	337.2 (33)
TE53	82.9 (37)	154.3 (28.5)	226.9 (43)	334.7 (34)
EE41	72.7 (49)	134.9 (42)	240.4 (34)	333.8 (35)
TT16	88.5 (23.5)	164.6 (12)	240.9 (33)	333.6 (36)
TT34	79.6 (44)	148.8 (35)	230.2 (40)	331.0 (37)
XLD-4-89	85.9 (31.5)	159.3 (18.5)	244.3 (32)	330.7 (38)
EJ16	82.1 (39)	132.5 (43)	231.2 (39)	328.2 (39)
TT62	77.4 (45)	150.8 (32)	234.1 (37)	327.4 (40)
TT35	83.2 (36)	152.6 (30)	236.1 (35)	322.8 (41)
EE21	73.2 (47)	129.0 (45)	228.4 (41)	315.5 (42)
JJ23	83.6 (34.5)	135.1 (41)	227.9 (42)	309.9 (43)
JJ64	85.9 (31.5)	131.6 (44)	207.6 (46)	301.0 (44)
JJ21	81.8 (40)	125.0 (47)	198.5 (50)	298.4 (45)
JJ26	85.8 (33)	125.7 (46)	211.7 (45)	296.5 (46)
TT41	76.5 (46)	138.0 (40)	212.2 (44)	295.7 (47)
EE14	68.9 (50)	112.1 (50)	198.6 (49)	293.2 (48)
JJ24	80.4 (43)	117.3 (48)	199.8 (47)	276.2 (49)
JJ63	83.6 (34.5)	110.7 (51)	199.4 (48)	275.7 (50)
XLD-7-89	66.2 (52)	108.0 (52)	171.4 (52)	267.1 (51)
JJ61	67.8 (51)	113.9 (49)	189.1 (51)	264.3 (52)

2 JxE families are in the bottom 50% of the test with heights below the test mean. Progeny testing is clearly vital to screen out poorly performing families, such as the *L. decidua* x *kaempferi* commercial check (von Lochow), which has ranked at the bottom for all families through five growing seasons. The observation that the mean height of trees in the adjacent operational plantation was below that of 28 families in the test emphasizes the need to replace the von Lochow hybrid as commercial planting stock perhaps with locally produced seed.

Progeny testing is vital for tree improvement programs in order to determine the breeding value of parent trees. In the case of the Johnson Mountain Township larch progeny test, hybrid vigor was demonstrated for all interspecific hybrids, and families with superior growth have been identified. Family selection within interspecific hybrids can increase the potential gain in height and volume, since the five tallest families in the test grew 6% to 12% more than the mean height of all interspecific hybrids (*Table 5*). These five families were between 19% to 26% and 30% to 37% taller than the mean height of intraspecific crosses and the two commercial checks, respectively. Gains in volume of over 100% may be achieved by selecting the best families in the test (*Table 6*).

Although hybrids between *L. decidua* and *L. kaempferi* are consistently ranked near the top for DBH, GLD, and height, interspecific hybrids involving *L. laricina* also have performed well in the test. In particular *L. laricina* x *decidua* hybrids showed great promise with 3 families in the top ten for height, and 5 out of 6 families having a height increment over a meter in 1996. Based on 5-year data it is clear that hybridization between *L. laricina* and *L. decidua* or *L. kaempferi* should continue to be investigated as stock for reforestation. *Larix laricina* x *decidua* hybrids were nearly 10% taller than either of the parent species and had 47% and 19% more volume than intraspecific crosses of *L. laricina* and *L. decidua,* respectively. *Larix laricina* x *kaempferi* hybrids were 10% and 27% taller and had 41% and 82% more volume than intraspecific crosses of *L. laricina* and *L. kaempferi,* respectively. However, the observation that the overall height rank of intraspecific *L. laricina* families has declined over 5 years is cause for concern (*Figure 4*). In Maine, *L. laricina* initially grows rapidly, but is not a long-lived species and rarely achieves large size. In addition, *L. laricina* appears to produce less diameter growth per unit of height growth than most of the other families (*Table 2*). The intra- and interspecific crosses involving *L. laricina* must be followed over time to see if the trend of decreased height growth over time continues. Since the results presented here represent a single test after only five growing seasons, some caution is advised in the interpretation of these results. Further hybridization research should be conducted in order to test the consistency of hybrid larch performance for reforestation and to evaluate current commercial planting stock.

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