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Extractives and Lignin Content Variation in Young Casuarina Trees Grown in Riyadh and Their Importance to Utilization

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Variation of extractives and lignin contents among and within five *Casuarina cunninghamiana* Miq windbreak trees was examined. Averages for water-soluble extractives (WSE), alcohol-soluble extractives (ASE), and total extractives (TE) were 3.47 ± 1.47%, 4.53 ± 2.22%, and 8.0 ± 3.04%, respectively. The tree-to-tree variation in WSE, ASE, and TE amounted to about 72.3%, 74.6%, and 83.3% of total variation, respectively. The study also revealed that the magnitude of extractives content did not change significantly according to side/height/tree, but did change significantly according to height within tree in the case of WSE only.

Lignin content was determined as Klason lignin and its average was 26.6 ± 3.91%. It varied from tree to tree and within each tree according to height above stump-level. About 48.1% of total variation was due to tree-to-tree variation, 14.8% to height within trees and only 4% to sides/height/trees.

The best reduced regression models that characterize the variation in extractives and lignin contents of individual trees were developed. In addition, the implication of the reported results with regard to the utilization of casuarina wood in arid zones was discussed.

The potential of casuarina as plantation species in Saudi Arabia is being increasingly recognized, mainly because of their fast growth rate and the protection they provide to various field crops. In addition to their main utilization as windbreaks and shelterbelts, casuarina trees can be used as a source of wood raw material. The possibility of utilizing these woods is being explored through the determination of their fundamental properties. In an earlier publication, Abo-Hassan and El-Osta

(1982) examined the type of variation in specific gravity (SG) and fibre length encountered within and among the *Casuarina cunninghamiana* Miq windbreak trees. SG and fibre length are two important parameters closely associated with wood quality and its end uses.

Chemically, wood cell walls are composed of three groups of structural substances—cellulose, hemicellulose, and lignin. Cellulose as the framework substance, contributes its high tensile strength to the complex of wood structure. The presence of hemicelluloses in the cell wall has a tremendous influence on certain physical properties of wood. The function of lignin is to provide rigidity and stiffness to cell walls.

In addition to its major chemical components, wood also contains small (but in some cases quite appreciable) quantities of extraneous components. These extractives exert a diversified influence on the characteristics of wood, wood products, and/or tissues. They are responsible for colour and fungicidal characteristics in wood (Hillis 1972) and cause surface inactivation to veneer (Hancock and Swan 1965). Other properties that have been related to extractive include sorption (Wangaard and Grandos 1967), shrinkage (Choong 1969), adhesion and wettability (Chen 1970), specific gravity and compressive strength (Badran and El-Osta 1977; El-Osta *et al.* 1980) and bending strength (Arganbright 1971).

It is well documented that the magnitude of these chemical constituents varies within a single tree from the centre of the stem to the bark, from the stump to the crown, between early- and latewood and between sapwood and heartwood (Kollmann and Cote 1968; Panshin and de Zeeuw 1970). Furthermore, information on the magnitude and variation of the chemical components of windbreak trees is a prerequisite for successful assessment of these properties and efficient conversion of wood into its end products. In addition, low within-tree variation in the chemical components is a desirable feature, indicating a raw material having a high degree of uniformity.

Very little information is available on the magnitude and variation of extractives and lignin content of casuarina windbreak trees. Therefore, the objective of this study was to evaluate the extractives and lignin contents of *Casuarina cunninghamiana* Miq and further to characterize the pattern of variation in these two important properties.

Materials and Methods

Five windbreak trees of *Casuarina cunninghamiana* were selected from about twelve-year-old plantation near the College of Agriculture building, King Saud

University. These trees had straight nonleaning stems and were free of any visible defects. The characteristics of these trees were given in an earlier paper by Abo-Hassan and El-Osta (1982). Selected trees were felled and cross-sectional discs, 5 cm thick, were removed at the stump-height, breast height, and at 1-m intervals until a diameter of 5 cm outside bark was reached. Discs were wrapped in polyethylene sheets and placed in a cold storage room (5 °C).

Specimen preparation

A diametrical strip (nominal, 3 cm tangentially and 6 cm longitudinally) was cut from each disc from north to south. Strips were then machined systematically into a number of specimen (nominal, 2.5 cm tangentially, 1 cm radially, and 6 cm longitudinally) at 1.5 cm interval from pith. One small section was removed from each end of individual specimens and used for determining fibre length, whereas the middle part used for specific gravity determination (Abo-Hassan and El-Osta 1982).

Extractives content determination

Specimens used for specific gravity determination were chipped and ground in a small Wiley mill. The particles that passed through a 20-mesh screen but were retained on a 40-mesh screen were collected in nylon bags, placed in weighing cans, and oven dried to constant weight. The nylon bags containing the wood meal were sequentially refluxed in a Soxhlet apparatus with ethyl alcohol 99.8% (8 h) and hot distilled water (4 h) with a change of water every hour. Oven-dry weight of the bags and their contents was also obtained after extraction with alcohol and distilled water (Browning 1967).

Alcohol-soluble and water-soluble extractive contents were calculated based on extractive-free oven-dry weight. It should be indicated that casuarina wood did not contain extractives that could be dissolved in benzene.

Lignin content determination

Lignin content was determined as Klason lignin using the Jayme, Konelle, and Rapp (1958) method as modified by Byrd (1964) and Byrd *et al.* (1965). Basically, the method involves a primary hydrolysis of the extracted wood meal with a mixture of phosphoric and sulphuric acids at 35 °C for 1 h followed by a secondary acid hydrolysis for 0.5 h. Lignin content was calculated as a percentage of the extractive-free oven-dry weight of the wood meal.

Statistical analysis

The water-soluble extractives (WSE), alcohol-soluble extractives (ASE), total extractives (TE), and lignin content data for each of the five selected trees were analysed separately using a nested design. The model was

$$X_{ijk} = U + E_i + B_{ij} + e_{ijk},$$

where

U = overall mean,

E_i = effect of height within tree,

B_{ij} = effect of side/height, and

e_{ijk} = effect of specimen/side/height = (error).

Then, the results of this analysis were combined for the five trees.

Expected mean squares were determined and the variance components were calculated. The harmonic mean was used to calculate the multipliers for components of variance because the variation in the number of trees, height, and specimens was small.

A second analysis was conducted using multiple regression with the least squares method fit for each tree. The model was

$$Y = a + b_1x_1 + b_2x_2 + b_3x_1^2 + b_4x_2^2 + b_5x_1x_2,$$

where

x_1 = height above stump-level (m),

x_2 = distance from pith (cm), and

Y = any of the dependent variables—WSE, ASE, TE, or lignin content.

A computer program was used to perform the regression analysis. Then, the best subsets of the independent variables that contributed significantly to the variation in extractives or lignin content within trees were chosen.

Results and Discussion

Extractives content

Average values and the range for WSE, ASE, and TE are presented in Table 1. The magnitude of within-tree variation in extractives content was

Table 1. Ranges, means, and coefficients of variation (CV) for water-soluble (WS), alcohol-soluble (AS), and total extractives (TE).

Tree No.		Range (%)	Mean (%)	CV (%)
1	WSE	2.14–5.37	3.89	21.91
	ASE	5.31–10.25	7.63	16.15
	TE	9.13–14.49	11.52	11.91
2	WSE	1.86–4.23	3.15	19.31
	ASE	2.47–8.48	5.54	27.60
	TE	5.25–12.48	8.69	19.86
3	WSE	0.97–3.88	2.36	31.07
	ASE	1.15–4.78	2.50	40.43
	TE	2.37–7.88	4.85	28.24
4	WSE	1.57–3.99	2.83	23.47
	ASE	1.35–5.00	3.25	29.80
	TE	3.19–8.62	6.09	18.56
5	WSE	3.23–7.95	5.74	23.01
	ASE	2.69–8.42	5.20	33.23
	TE	7.45–15.28	10.94	15.87

examined by computing the coefficient of variation (CV). The CV for WSE, ASE, and TE for tree number 3 were comparatively the highest among the trees used.

The results of the statistical analysis using the nested design are presented in Table 2. Statistically significant differences in WSE, ASE, and TE were found among trees (Tables 2–4). However, no significant differences were found between heights within trees except in the case of WSE (Table 2). In addition, the difference in WSE, ASE, or TE between sides within heights of each tree was not significant.

Table 2. Analysis of variance and estimated mean square (EMS) for water-soluble extractives.

S.O.V.	D.F.	M.S.	F	E.M.S.
Trees (T)	4	57.408	45.30**	$\sigma_p^2+2.261\sigma_S^2+4.522\sigma_H^2+24.859\sigma_T^2$
Heights (H)/T	23	1.267	2.65**	$\sigma_p^2+2.261\sigma_S^2+4.522\sigma_H^2$
Sides (S)/H/T	28	0.479	$0.69^{N.S.}$	$\sigma_p^2+2.261\sigma_S^2$
Specimens/S/H/T	106	0.691		σ_p^2
Total	161			

σ_p^2, σ_S^2, σ_H^2, σ_T^2 are the variance components for error, S/H/T, H/T, and trees, respectively; their respective values are 0.691, 0, 0.1747, and 2.2584.

** Significant at the 1% level of probability.

N.S., not significant.

Table 3. Analysis of variance and expected mean square (E.M.S.) for alcohol-soluble extractives.

S.O.V.	D.F.	M.S.	F	E.M.S.
Trees (T)	4	132.160	55.72**	$\sigma_p^2 + 2.261\sigma_S^2 + 4.522\sigma_H^2 + 24.859\sigma_T^2$
Heights (H)/T	23	2.372	$1.23^{\text{N.S.}}$	$\sigma_p^2 + 2.261\sigma_S^2 + 4.522\sigma_H^2$
Sides (S)/H/T	28	1.936	$1.31^{\text{N.S.}}$	$\sigma_p^2 + 2.261\sigma_S^2$
Specimens/S/H/T	106	1.477		σ_p^2
Total	161			

$\sigma_p^2 = 1.4768$, $\sigma_S^2 = 0.2031$, $\sigma_H^2 = 0.0964$, and $\sigma_T^2 = 5.221$.
See Table 2 for legends.

Variance components for extractives content are presented in Tables 2–4. It can be seen that 72.3%, 74.6%, and 83.3% of total variation in WSE, ASE, and TE, respectively, was attributed to tree-to-tree variation. This large tree-to-tree variation in extractives content of *Casuarina cunninghamiana* wood is an encouraging indication that selection might be effective in changing this wood characteristic. This is in agreement with work carried out by Sluder (1972) on the specific gravity of yellow poplar (*Liriodendron tuliprifera* L.) and by Abo-Hassan and El-Osta (1982) on the specific gravity and fibre length of *C. cunninghamiana*.

With regard to WSE, it was found that the differences between heights within trees were significant (Table 2). The change in WSE with height for each tree is shown in Fig. 1. The change with height in WSE of casuarina wood, a diffuse porous species, differs from tree to tree.

Variation in extractives content within individual trees

The best reduced regression models that characterize the pattern of variation in WSE, ASE, and TE within each tree are given in Table 5.

Table 4. Analysis of variance and expected means square (E.M.S.) for total extractives.

S.O.V.	D.F.	M.S.	F	E.M.S.
Trees (T)	4	287.179	80.66**	$\sigma_p^2 + 2.261\sigma_S^2 + 4.522\sigma_H^2 + 24.859\sigma_T^2$
Heights (H)/T	23	3.561	$1.45^{\text{N.S.}}$	$\sigma_p^2 + 2.261\sigma_S^2 + 4.522\sigma_H^2$
Sides (S)/H/T	28	2.449	$1.36^{\text{N.S.}}$	$\sigma_p^2 + 2.261\sigma_S^2$
Specimens/S/H/T	106	1.799		σ_p^2
Total	161			

$\sigma_p^2 = 1.7991$, $\sigma_S^2 = 0.2492$, $\sigma_H^2 = 0.2457$ and $\sigma_T^2 = 11.4091$.
See Table 2 for legends.

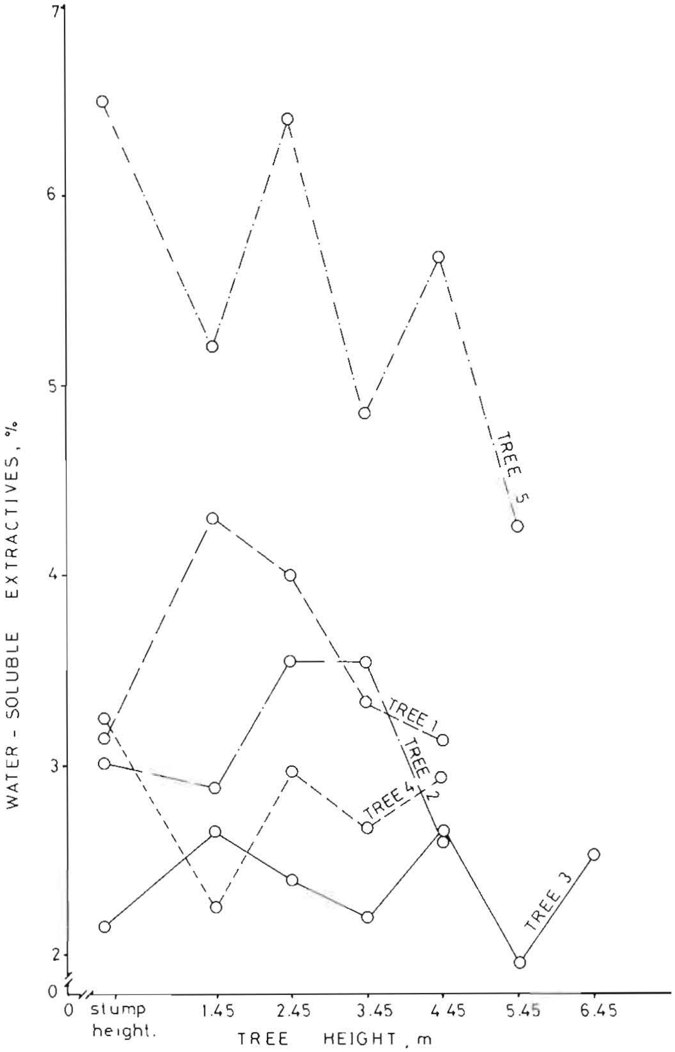

Fig. 1. **Effect of height on water-soluble extractives content for each of five study trees.**

In the case of tree number 1, none of the tree parameters, i.e. height (H) or its second order (H^2), distance from pith (D) or its second order (D^2), or $D \times H$ seem to affect the variation in WSE. The best reduced regression model for the variation in ASE included D^2 and HD. These two parameters together accounted for about 34% of total variation. In addition, the model for TE contained D^2 only and it accounted for about 23% of total variation. It is obvious from this model that TE increased nonlinearly with distance from pith.

Table 5. Best reduced regression models for representing the variation in water-soluble extractives (W.S.E.), alcohol-soluble extractive (A.S.E.), and total extractives (T.E.).

Tree No.		Model	N	SE_E	r
1	WSE	None of the independent parameters was significant.			
	ASE	$Y = 6.42 + 0.047D^{2*} + 0.16HD^{*}$	26	1.04	0.584
	TE	$Y = 10.80 + 0.065D^{2**}$	26	1.23	0.479
2	WSE	$Y = 2.88 + 0.06HD^{*}$	30	0.58	0.366
	ASE TE	None of the independent parameters was significant.			
3	WSE	$Y = 1.93 + 0.12D^{*}$	44	0.70	0.318
	ASE	$Y = 2.21 - 0.78H^{*} + 0.75D^{*} + 0.12H^{2**} - 0.095D^{2*}$	44	0.91	0.513
	TE	None of the independent parameters was significant.			
4	WSE	None of the independent parameters was significant.			
	ASE	$Y = 3.68 - 0.23H^{*}$	32	0.92	0.361
	TE	$Y = 7.09 - 1.20H^{**} + 0.21H^{2*}$	32	0.97	0.559
5	WSE	None of the independent parameters was significant.			
	ASE	$Y = 8.75 - 0.58H^{**} - 0.78D^{**}$	30	1.38	0.635
	TE	$Y = 14.80 - 0.83H^{**} - 0.70D^{**}$	30	1.18	0.754

H = height above stump-level, m.
D = distance from pith, cm.
N = number of measurements.
SE_E = standard error of estimate.
r = correlation coefficient.
* = significant at the 5% level of probability.
** = significant at the 1% level of probability.

Table 5 reveals that, in the case of tree number 2, the magnitude of neither ASE nor TE changed significantly according to any of the tree parameters used. However, WSE was significantly affected by *DH*. It accounted for about 13.4% of total variation.

With regard to tree number 3, it was found that WSE increased significantly as the distance from pith (*D*) increased (Table 5) and that about 10% of total variation can be accounted for by this parameter alone. In addition, the best reduced model for ASE contained *H*, *D*, and their second orders (Table 5). About 26% of total variation was attributed to these four parameters. However, none of the tree parameters used seem to affect the magnitude of total extractive significantly.

None of the independent tree parameters contributed significantly to the variation in WSE of tree number 4. However, WSE was inversely correlated with height

Table 6. Ranges, means, and coefficient of variation (CV) for lignin content.

Tree No.	Range (%)	Mean (%)	CV (%)
1	14.67-29.17	21.20	20.72
2	23.18-30.21	26.43	7.91
3	21.97-32.66	28.05	10.80
4	22.79-36.76	26.67	8.46
5	21.30-35.67	29.12	10.36

above stump-level ($r = 0.361$) and about 13% of the variation in ASE was attributed to height. Furthermore, the best regression model that characterized the pattern of variation in TE included H and its second order. These two parameters explain about 31% of total variation (Table 5).

The WSE of tree number 5 did not change significantly with any of the independent parameters (Table 5). However, the best reduced regression model for ASE and TE included H and D together. These models accounted for 40.3% and 56.9% of total variation in ASE and TE, respectively.

Lignin content

Average values and ranges for lignin content along with the CVs for the five trees are given in Table 6. The highest CV was obtained in the case of tree number 1.

The results of the statistical analysis using the nested design are presented in Table 7. It can be seen that the lignin content of the five study trees differed significantly. In addition, the lignin content varied significantly at different heights

Table 7. Analysis of variance and expected mean square (E.M.S.) for lignin content.

S.O.V.	D.F.	M.S.	F.	E.M.S.
Trees (T)	4	243.291	11.79**	$\sigma_p^2 + 2.146\sigma_S^2 + 4.292\sigma_H^2 + 23.595\sigma_T^2$
Heights (H)/T	23	20.644	2.52*	$\sigma_p^2 + 2.146\sigma_S^2 + 4.292\sigma_H^2$
Sides (S)/H	28	8.191	1.26$^{N.S.}$	$\sigma_P^2 + 2.146\sigma_S^2$
Specimens/S/H/T	96	6.508		σ_p^2
Total	151			

$\sigma_p^2 = 6.508$, $\sigma_S^2 = 0.784$, $\sigma_H^2 = 2.901$ and $\sigma_T^2 = 9.436$.
See Table 2 for legends.

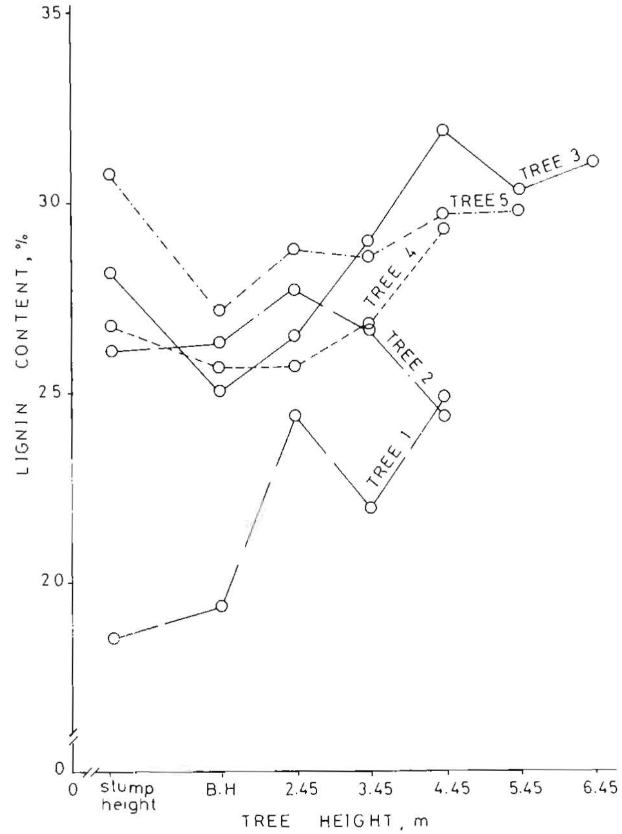

Fig. 2. Effect of height on lignin content for each of five study trees.

within trees. This relationship is shown in Fig. 2. Generally, there was an inconsistent increase in lignin content as the height increased, except in the case of tree number 2. The lignin content did not vary significantly with the side of the tree from which specimens were taken.

The calculated variance components are presented in Table 7. It can be seen that about 48.1% of the total variation in lignin content was attributed to differences among trees. This relatively large tree-to-tree variation of casuarina wood is also an encouraging indication that selection for individual trees might be effective in the tree improvement program. This trend had been reported for other properties of casuarina wood (Abo-Hassan and El-Osta 1982). In addition, about 14.8% of

Table 8. Best reduced regression models for representing the variation in lignin content (Y).

Tree No.	Model	N	SE_E	r
1	$Y = 18.57 + 0.60HD^{**}$	24	3.84	0.520
2	$Y = 27.25 - 0.05D^{2*}$	30	1.96	0.394
3	$Y = 28.99 + 0.09H^{2*} - 0.50D^{*}$	40	2.45	0.617
4	$Y = 26.96 - 1.90H^{*} + 0.54H^{2**}$	28	1.97	0.544
5	None of the independent parameters was significant.			

See Table 5 for legends.

the total variation in lignin content was accounted for by the variation in heights within trees. This indicates that the height is the second major source of variability in lignin content.

Variation in lignin content within individual trees

The best reduced regression models that represent the variation in lignin content within trees are given in Table 8. The model for tree number 1 contained the parameters *HD* and explained about 27% of total variation. In the case of tree number 2, lignin content decreased nonlinearly with D ($r = 0.394$). The model for tree number 3 included the second orders of H and D. This model accounted for 38% of total variation. The best reduced model for tree number 4 contained H and its second order and accounted for about 30% of total variation. On the other hand, none of the tree parameters affected the magnitude of lignin content of tree number 5 significantly (Table 8).

Windbreak trees in arid and semiarid countries like Saudi Arabia are considered a major source for wood. The present and a previous study (Abo-Hassan and El-Osta 1982) shed some light on the possibility of utilizing casuarina wood by determining and assessing variation of its basic properties. The present results indicated that the tree-to-tree variation in extractives and lignin content constituted the major component of variation in this diffuse-porous wood. This would encourage the selection of trees with high lignin content if the wood is to be exposed to compression strength parallel to grain and choosing trees with high extractives content if resistance to applied compression strength and durability to fungus attack are required.

With regard to variation in the properties under consideration with height within trees, it was found that this component was not significant except in the case of water-soluble extractives and lignin content. The implication of these results is that one can select the specific height of the tree at which the WSE and/or lignin content are the highest, if this criterion is required for the industrial utilization of casuarina wood.

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تباين نسبة المستخلصات واللجنين فى أشجار الكازوارينا الصغيرة العمر فى الرياض وأهميتها بالنسبة للاستعمالات

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لقد فحص التباين فى نسبة المستخلصات واللجنين بين وداخل خمسة أشجار من الكازوارينا *Casuarina cunninghamiana* النامية كمصدات رياح ٠

أوضحت هذه الدراسة أن متوسط نسبة المستخلصات الذائبة فى الماء هى ٣ر٤٧ ± ١ر٤٧ ٪ والذائبة فى الكحول هى ٤ر٥٣ ± ٢ر٢٢ ٪ وأن متوسط نسبة المستخلصات الكلية حوالى ٨ ± ٣ر٠٤ ٪ ٠

اختلفت نسبة المستخلصات جوهريا من شجرة الى أخرى ٠ وبينت الدراسة أن حوالى ٧٢ر٣ ٪ ، ٧٤ر٦ ٪ ، ٨٣ر٣ من الاختلافات الكلية فى نسبة المستخلصات الذائبة فى الماء ، فى الكحول ، الكلية على التوالى يرجع الى الاشجار الفردية ٠ وأوضحت الدراسة أيضا أن نسبة المستخلصات الذائبة فى الكحول والكلية لم تتأثر بتغير الارتفاع أو الاتجاه داخل الشجرة ٠

تم تقدير اللجنين فى صورة كلاسون لجنين ، وكان متوسطه ٢٦ر٦ ± ٣ر٩١ ٪ ، ولقد اختلفت نسبة اللجنين جوهريا من شجرة الى أخرى وأيضا داخل الشجرة على حسب الارتقاع ٠ وأوضح التحليل الاحصائى أن حوالى ٤٨ر١ ٪ من التباين الكلى فى نسبة اللجنين يرجع الى الاشجار الفردية ومن ناحية أخرى وجد أن حوالى ١٤ر٨ ٪ من هذا التباين يرجع الى الارتفاع داخل الشجرة ووجد أيضا أن حوالى ٤ ٪ من هذا التباين

يعزى الى الاتجاه الذى أخذت منه العينات داخل الشجرة .

ولقد تم التوصل الى أفضل معادلات الارتداد التى تمثل التباين فى كل من نسبة المستخلصات واللجنين ، بالاضافة الى ذلك نوقشت النتائج المتحصل عليها فى ضوء استعمالات أخشاب الكازوارينا النامية كمصدات رياح فى المناطق الجافة .