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Usefulness of multivariate analysis in forestry research: A case study of *Pinus roxburghii*

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Abstract
Although resin yield may depend on a variety of characteristics, the researchers are always interested in identifying those sets of attributes which most significantly affect the resin yield of the tree. Multivariate statistical techniques are such advanced techniques that help in identifying such set of attributes. The paper deals with the application of multivariate techniques to assess the relative contribution of morphological characters in the resin production of *Pinus roxburghii*.

Keywords: principal component and factor analyses, resin, *Pinus roxburghii*

Introduction
Multivariate analysis comprises advanced techniques for examining relationships among multiple variables at the same time. Multivariate analysis takes into account the inter-dependence and relative importance of the various characters involved and yield more meaningful information (Morrison, 1976) [4]. The multivariate techniques allow simultaneous analysis of multiple measurements of individuals being investigated (Hair *et al*., 1987) [2]. With the advances in computer programming, multivariate techniques (Discriminant Analysis, Principal Component Analysis, Factor Analysis and Canonical Correlation) are increasingly being used in the analysis of biological data.
The aim of undertaking multivariate analysis is to reduce the number of variables by employing suitable linear transformation and choose a very limiting number of the resulting linear combinations in some optimum manner, disregarding the remaining linear combinations in the hope that they do not contain much significant information. Thus the dimensionality of the problem is reduced. Today, these techniques are being applied in many fields, especially when the variables concerning research studies of these fields are supposed to be correlated with each other and when rigorous probabilistic models cannot be appropriately used.
Resin is one of the oldest renewable forest products. Chir pine yields a good quality oleo resin, which on steam distillation generates two industrially important products viz., turpentine oil and rosin. Turpentine oil holds a wide variety of industrial uses in perfumery industry, pharmaceutical preparations, synthetic pine oil, disinfectants and denaturants. Keeping in view the economic importance of the resin, the present investigation was carried out to assess the relative contribution of morphological characters in the resin production of *Pinus roxburghii* using Principal Component and Factor Analyses.

Methodology
The present investigation was carried out in the field of the Department of Forest Products, Dr Y S Parmar University of Horticulture & Forestry, Nauni, Solan Himachal Pradesh during the year 2015-2016. The experimental area is located in the mid hill zone of Himachal Pradesh with an elevation of about 900-1300m above mean sea level. The area lies about 13 km from Solan, between latitude 30º50´30" to 30º50´0" N latitude and the longitude 77º8´30" and 77º11´30" E (Survey of India Toposheet No. 53F/1) according to Survey of India. Plantations of *Pinus roxburghii* at the main campus of the Dr. Y S Parmar University of Horticulture and Forestry, Nauni were selected for the study.
The data on various growth characteristics viz., Diameter at breast height – DBH (cm), Tree height (m), Bole height (m), Bark Thickness (cm), Crown width (m), Number of primary branches, Needle length (cm), Needle thickness (mm), Leaf area index, Mean leaf angle, Transmission coefficient and Resin Yield were recorded. Resin yield of 80 trees of *Pinus roxburghii* was taken from the Department of Forest Products, Dr. Y.S. Parmar University of Horticulture and Forestry, Nauni Solan, Himachal Pradesh. Principal Component and Factor

Analyses were carried out to find out the basic components associated with the above referred morphological characters of *Pinus roxburghii*.

Result and Discussion

Characteristics of *Pinus roxburghii* evaluated during 2015-16 planting season at Nauni, Solan are presented in Table 1. Mean Resin yield (gm) was found to be 1728.96 gm with 95% fudicial limits 1225.30-2232.70 gm.

Table 1: Characteristics of *Pinus roxburghii* during 2015-16 planting season

Characteristics	Mean	SE	95% Fudicial limits
Height (m)	21.517	1.60	18.381-24.653
Bole height (m)	8.432	0.65	7.158-9.706
Bark thickness (cm)	6.285	0.47	5.364-7.206
Crown width (m)	9.890	0.66	8.596-11.184
Number of branches	36.515	1.05	34.457-38.573
Needle length (cm)	20.342	1.76	16.892-23.791
Needle thickness (mm)	0.948	0.06	0.831-1.066
Leaf area index	0.520	0.05	0.422-0.618
Transmission coefficient	0.677	0.03	0.617-0.736
Mean leaf angle	33.485	1.32	30.898-36.072
Resin yield (gm)	1728.96	256.99	1225.30-2232.70

Mean Height (m), Bole height (m), Bark thickness (cm), Crown width (m), Number of branches, Needle length (cm), Needle thickness (mm), Leaf area index, Transmission coefficient and Mean leaf angle were 21.517 m, 8.432 m, 6.285 cm, 9.890 m, 36.515, 20.342 cm, 0.948 mm, 0.520, 0.677 and 33.485 with 95% fudicial limits 18.381-24.653 m, 7.158-9.706 m, 5.364-7.206 cm, 8.596-11.184 m, 34.457-38.573, 16.892-23.791 cm, 0.831-1.066 mm, 0.422-0.618, 0.617-0.736, and 30.898-36.072 respectively.

Principal component analysis

Perusal of Table 2 reveals that two of the eleven principal components (PCs) have eigen values greater than unity and as such these two principal components play the main role in the analysis. The components explain 48.372 per cent and 13.468 per cent, of the total variation respectively. Together, they accounted for 61.840 per cent of the total variation of the original variables. The variables loadings for first principal component were highest for three characters i.e. diameter (DBH), bark thickness and height.

Table 2: Eigen vectors of the PC analysis

Characters	PC1	PC2
Diameter (cm)	0.408	0.003
Height (m)	0.374	0.046
Bole Height (m)	0.233	0.156
Bark Thickness (cm)	0.394	-0.081
Crown Width	0.326	0.037
Number of Branches	0.279	0.265
Needle Length	0.327	-0.175
Needle Thickness (mm)	0.287	-0.346
Leaf Area Index	0.279	-0.282
Transmission coefficient	0.166	0.495
mean leaf angle	0.068	0.648
Eigen value	5.321	1.481
% of variance	45.372	13.468
Com. % of variance	45.372	68.840

However, the second principal component is a combination of transmission coefficient and mean leaf angle. Thus, the main contributors towards resin yield of *Pinus roxburghii* on basis of PC analysis are tree height, diameter and bark thickness followed by transmission coefficient and mean leaf angle.

Factor analysis: The primary field data were used for factors extraction through Principle Component method. Two factors, F_1 and F_2 have been retained in the analysis by virtue of mineigen criteria (i.e., factors having eigen value greater than one). The variation explained by these two factors F_1 and F_2 was 45.116 per cent and 7.954 per cent respectively. Ignoring the non-significant correlations, the orthogonal factor can be expressed as:

$$F_1 = 0.432X_1 + 0.380X_2 + 0.412X_4$$

Factor (F_1) was a combination of DBH (X_1), tree height (X_2) and bark thickness (X_4) and can be considered as bole characteristics. The communalities (common factor coefficient) of the variates viz, DBH, tree height and bark thickness were observed to be 0.896, 0.687 and 0.861 respectively.

$$F_2 = 0.436X_{11}+0.639X_{10}$$

Factor (F_2) was a combination of transmission coefficient (X_{11}) and mean leaf angle (X_{10}) and second factor can be considered as canopy characteristics. The communalities (common factor coefficient) of the variates viz. transmission coefficient and mean leaf angle were observed to be 0.276 and 0.324. Holland (1969) [3] has discussed some applications of multivariate methods viz. Principal Component and Factor Analysis on observations made on tree crops. Chernudubov (1994) [1] used Factor Analysis for studying the morpho-anatomical traits of *Ulmus villosa* in Insular Pine Forest of the South Russian Plain.

Summary: Two principal components were retained which together accounted for 61.840 per cent of the total variation. In factor analysis, two factors were extracted by virtue of mineigen criteria. Thus, the Principal Component Analysis has brought out some of the basic components associated with morphological characters of *Pinus roxburghii* and could be considered as important tool in explanatory work for optimizing resin productivity

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