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Original article

Phenotypic variability of *Anacardium excelsum* plantation in Espinal, Colombia

Variabilidad fenotípica de la plantación de *Anacardium excelsum* en El Espinal, departamento del Tolima, Colombia

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ABSTRACT: The native species *Anacardium excelsum* Skeels has economic and ecological importance for its nutritional use, timber use, and for its contribution in the protection of water resources. However, the morphological traits with the greatest contribution to phenotypic variability are unknown, a key aspect for the selection of plus trees and identification of their potential for use. In the plantation of Nataima Research Center of AGROSAVIA in El Espinal, department of Tolima-Colombia, was evaluated the phenotypic variability in 86 trees by using 32 quantitative and qualitative plant descriptors. Statistical methods included frequency analysis of qualitative descriptors, multiple correspondence analysis, and principal components for qualitative and quantitative descriptors respectively, complemented by a cluster analysis. 14 tree descriptors (tree bole and tree crown) were identified that provide more information about the phenotypic variability of the species. The individuals were characterized by having a predominantly ellipsoid shape, an extent habit, a cylindrical shaft without deformations and some curvatures in more than one plane, angle ramification, partial dominance of the initial axis over the lateral branches, angle of insertion of branches between 31 and 60°, ovoid tree crown in the vertical profile and irregular circular in the horizontal profile, intermediate tree crown density and smooth bark with vertical lines. In the *A. excelsum* plantation, individual with timber potential of use and silvopastoral systems of scattered trees in pastures, living fences or windbreaks were identified.

Key Words: Forest genetic resources, leaves, plant morphology, phenotypes, tropical wood.

RESUMEN: La especie nativa *Anacardium excelsum* Skeels tiene importancia económica y ecológica por su uso alimenticio, maderable y su aporte en la protección de recursos hídricos. Sin embargo, se desconocen los rasgos morfológicos de mayor aporte en la variabilidad fenotípica, aspecto clave para la selección de árboles sobresalientes e identificación de su potencial de uso. En la plantación del Centro de Investigación Nataima de AGROSAVIA en El Espinal, departamento de Tolima-Colombia, se evaluó la variabilidad fenotípica en 86 árboles empleando 32 descriptores cuantitativos y cualitativos de la planta. Los métodos estadísticos incluyeron análisis de frecuencias de descriptores cualitativos, análisis de correspondencias múltiples y componentes principales para descriptores cualitativos y cuantitativos respectivamente, complementado con un análisis de conglomerados. Se identificaron 14 descriptores de árbol (fuste y copa) que aportaron más información sobre la variabilidad fenotípica de la especie. Los individuos se caracterizaron por presentar forma predominantemente elipsoide, hábito extendido, fuste cilíndrico, sin bifurcaciones y con algunas curvaturas en más de un plano, ramificación acodillada, dominancia parcial del eje inicial sobre las ramas laterales, ángulo de inserción de ramas entre 31 y 60°, copa de forma ovoide en el perfil vertical y circular irregular en el perfil horizontal, densidad de copa intermedia y corteza lisa con surcos verticales. En la plantación de *A. excelsum* se identificaron individuos con potencial de uso maderable y sistemas silvopastoriles de árboles dispersos en potreros, cercas vivas o barreras rompevientos.

Palabras clave: hojas, fenotipos, madera tropical, morfología vegetal, recursos genéticos forestales.

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INTRODUCTION

Anacardium excelsum Skeels (caracolí) is a native forest species of the Anacardiaceae family, of great timber and ecological importance. In Colombia, *A. excelsum* is a near-threatened species according to its conservation status and is distributed in the Caribbean Plain, Orinoquia, and Pacific, Sierra Nevada de Santa Marta, Valle del Cauca and Valle del Magdalena (1). It inhabits tropical dry forest (bs-T), tropical humid forest (bh-T), premontane humid forest (bh-PM) and very humid premontane forest (bmh-PM) (2). It is a durable heliophyte species, used in ecological restoration (3) and has been reported in bs-T fragments in extensive cattle ranching landscapes in the department of Córdoba, Colombia (4).

A. excelsum has light and easy to work wood, used in construction (interiors), manufacture of boxes or crates (5), boats, paddles, ordinary furniture, formaletas, rafts and pylons (6), canoes, crates and cattle feeders, insulators and triplex veneers because it is easy to plane (2). Also as human food (roasted seeds), manufacture of varnishes and lacquers, insecticides (7), utensils and fuel (8). As a melliferous plant it is useful for beekeeping and is planted to protect the banks of rivers, lakes and lagoons; it serves as shade for coffee and cocoa plants (2).

In forest species, phenotypic traits have been the object of interest in breeding programs and characterization of genetic resources. Thus, genetic parameters of wood quality, growth and branching have been evaluated in *Pinus patula* (9), phenotypic characteristics of growth and fruit production in *Geoffroea decorticans* for the selection of plus trees (10), morphological variability of fruits and seeds in *Caesalpinia spinosa* (11) and repeatability of growth variables and morphological characters of stem and crown in *Cedrela odorata* (12). The evaluation of crown morphometry in *Prosopis alba* (13), as well as stem and crown in commercial species (14), the estimation of individual leaf area in *Swietenia macrophylla* (15), leaf morphology in species of the genus *Iryanthera* (16), spatial variation in leaf morphometry in mangroves (17), morphology of vegetative and reproductive organs in *Cinchona officinalis* (18) and leaf traits in *Cleome arborea*, *Weinmannia mariquitae*, *Viburnum triphyllum* and *Leandra subseriata* (19). In forest plantations, plant and leaf morphological traits have been evaluated in *Simarouba amara*, *Cassia moschata*, *Mimosa trianae*, *Cavanillesia platanifolia* and *Alnus acuminata* (20-23).

In *A. excelsum*, studies on rain interception (24), seed morphology (25), plant propagation (26), litter decomposition (27) and dendrochronology (28) stand out. The ecological, cultural and economic importance of the species merits identifying the phenotypic variability and the potential use of the outstanding individuals of the plantation of the Colombian Agricultural Research Corporation - AGROSAVIA, as a source of future plant material. The results of the study provide knowledge about the species under monoculture conditions.

MATERIALS AND METHODS

Study area and genetic material

The forest species plantation of the Nataima Research Center of AGROSAVIA is located in the warm valley of the upper Magdalena in El Espinal municipality, department of Tolima, Colombia. The area corresponds to the influence zone of Coello river irrigation district (USOCOELLO) and according to Holdridge the life zone corresponds to the tropical dry forest (bs-T). It is located at coordinates 4°11'45"N and 74°58'00" W, at 376 meters above sea level, on flat, flat terrain with a slope of less than 3 %. Climatic conditions are characterized by an average temperature of 28.2 °C, average rainfall of 1275 mm and average relative humidity of 69.40 %. It consists of 86 *A. excelsum* trees, planted at a distance of 4x3 m. The plant material propagated by seed was acquired from a commercial nursery, without distinction of origin and progeny.

Procedure

For morphological characterization, trees of 5.3 years of age were evaluated, using 32 descriptors: tree height, crown height, crown length (north-south direction), crown length (east-west direction), diameter at breast height, trunk volume, crown diameter, tree shape, tree growth habit, stem shape, stem straightness, tree branching, branching height, forking height, main axis dominance, branch insertion angle, crown shape (vertical profile), crown shape (horizontal profile), crown density, bark type, trunk color, trunk color, leaf shape, leaf margin, leaf apex, leaf base, petiole length, petiole thickness, leaf length, leaf width, leaf area, color of mature leaves on the upper side, color of mature leaves on the lower side (29).

The tree descriptors were evaluated in the complete plantation and the foliar descriptors were evaluated in 38 trees in which 10 simple mature leaves were collected per tree, with complete foliar laminae and without phytosanitary problems. The leaf area variable, fundamental in physiological studies (30), was calculated using the free software ImageJ designed for scientific image processing (31). The volume of the standing tree (Vol_trunk) and the approximate crown diameter (D_canopy) (32) were calculated from the formulas (1 and 2).

$$Vol\_trunk = \pi/4 * DAP^2 * HC * f \qquad (1)$$

Where:

DAP = Diameter at 1.3 m above ground level (cm) HC = Commercial height (m) F = Shape factor (0.75).

$$D\_top = (LCNS + LCEW)/2 \qquad (2)$$

Where:

LCNS = length of canopy north - south (m), LCEW = length of canopy east - west (m)

Statistical analysis

Frequency analysis was performed for qualitative variables and to reduce the dimensionality of the data set, multiple correspondence analysis (MCA) was performed for qualitative variables, using the CORRESP procedure (SAS Enterprise Guide V. 8.3) and principal component analysis (PCA) for quantitative variables, using the PRINCOMP procedure. Subsequently, based on the dimensions selected in the two previous statistical procedures, a cluster analysis (CA) was performed to classify individuals into homogeneous groups using the CLUSTER procedure (Ward's algorithm) (33). For each of the groups formed, basic statistics were generated to characterize them.

RESULTS AND DISCUSSION

In *A. excelsum* plantation, trees were observed to have angled branching, ovoid (vertical profile) and irregular circular (horizontal profile) crowns, intermediate crown density and green foliage (Table 1). Trees had an average total height of 14.6 m, DBH of 24.75 cm, trunk volume of 0.55 m^3, and crown diameter of 7.29 m (Table 2).

Table 1. Predominant categories in qualitative descriptors evaluated in the collection of *A. excelsum* (El Espinal, Tolima)

Descriptor	Predominant class
FARB	Ellipsoid (100 %)
HABARB	Extended (96.51 %)
FFU	Cylindrical (100 %)
RFU	Some curvatures in more than one plane (44.19 %)
RAM	Angled (96.51 %)
HRAM	In the lower third (80.23 %)
HB	Not bifurcated (94.19%)
DEP	Partial of the initial axis on lateral branches (95.35%)
AIR	≥ 31° and 60° (88.37%)
FCV	Ovoid (86.05%)
FCH	Circular irregular (65.12%)
DNC	Intermediate (76.74%)
TCORT	Smooth. vertically furrowed (97.67%)
CT	2.5Y6/2; 2.5Y5/2 (32.56%)
FH	Oblanceolate (100%)
BORH	Whole (100%)
APH	Rounded (38.79%)
BH	Acuminate (100%)
CHMHAZ	7.5GY (77.57%)
CHMENV	5GY (75.73%)

Where: FARB (tree shape), HABARB (tree growth habit), FFU (stem shape), RFU (stem straightness), RAM (tree branching), HRAM (branching height), HB (bifurcation height), DEP (Dominance on main axis), AIR (branch insertion angle), FCV (crown shape in vertical profile), FCH (crown shape in horizontal profile), DNC (crown density), TCORT (bark type), CT (trunk color), FH (leaf shape), BORH (leaf edge), APH (leaf apex), BH (leaf base), CHMHAZ (color of mature leaves on the upper side) and CHMENV (color of mature leaves on the lower side)

Table 2. Mean values and confidence intervals for the quantitative variables evaluated in *A. excelsum* (El Espinal, Tolima)

Descriptor	Mean	LIC	LSC
HT (m)	14.60	14.31	14.88
HC (m)	11.46	11.17	11.74
LCNS (m)	7.44	7.15	7.73
LCEW (m)	7.15	6.90	7.40
DBH (cm)	24.75	23.88	25.62
Vol_Trunk (m^3)	0.55	0.51	0.59
D_Cop (m)	7.29	7.05	7.54
LPEC (mm)	17.92	17.05	18.80
GPEC (mm)	4.43	4.27	4.59
LH (cm)	22.49	21.66	23.34
ANH (cm)	8.21	7.94	8.47
AFOLIAR (cm^2)	153.91	133.63	174.19

Where: HT (tree height), HC (crown height), LCNS (crown length north-south), LCEW (crown length east-west), DBH (diameter at breast height), Vol_Trunk (trunk volume), D_Cop (crown diameter), LPEC (petiole length), GPEC (petiole thickness), LH (leaf length), ANH (leaf width), AFOLIAR (leaf area), LIC (lower limit of confidence interval) and LSC (upper limit of confidence interval)

The qualitative variables evaluated in *A. excelsum*, presented similarities to those mentioned by other authors, thus complementing the description of the species: round crown trees, dense and dark green foliage, thick and abundant branches (2), straight and cylindrical stem, with sometimes deep vertical fissures (34). The 5.3-year-old plantation of *A. excelsum* presented trees with an average total height of 14.60 m, crown height of 11.46 m and DBH of 24.75 cm; leaves with petioles 17.92 mm long (LPEC) and leaflets 22.49 cm long (LH) and 8.21 cm wide (ANH) (Table 2). These values are similar to those reported for the species: leaves “25 cm long by 7 cm wide” (2).

On the other hand, in the absence of leaf area reports for *A. excelsum*, the measurement of 380 mature leaves in the plantation yielded an average value of 153.91 ± 25.58 cm^2 (Table 2) using digital image processing. This procedure has been carried out in species such as *Anacardium occidentale* with the ImageJ program, whose results classify as extra-large leaves those with an average value of 117.14 cm^2 (35). However, to establish size categories for *A. excelsum* leaves in the plantation, it would be necessary to evaluate the total number of individuals present and also include young leaves, thus obtaining more complete data that would contribute to the description of the species and the discrimination of groups.

As a result of the MCA of the qualitative tree descriptors, the first five dimensions were selected for *A. excelsum*, which accumulated 96.27 % of the variability contained (Table 3). The PCA based on the correlation matrix allowed the selection of the first five principal components (PC) for *A. excelsum*, which accumulated 99.78 % of the variability contained in the original quantitative variables. From this analysis, it was identified that in *A. excelsum* the variables with the greatest contribution in the discrimination of the trees were DBH, Vol_trunk, D_tree, HT and HC.

Tabla 3. Mean values and confidence intervals per cluster, for the quantitative variables evaluated in *A. excelsum* (El Espinal, Tolima)

Variable	Group 1 (n=10)			Group 2 (n=28)			Group 3 (n=17)			Group 4 (n=17)			Group 5 (n=14)		
	LIC	LSC	Mean	LIC	LSC	Mean	LIC	LSC	Mean	LIC	LSC	Mean	LIC	LSC	Mean
HT (m)	13.71	14.61	14.16	14.79	15.13	14.96	13.98	15.07	14.52	15.75	16.37	16.06	11.86	13.11	12.48
HC (m)	10.67	12.25	11.46	11.11	12.04	11.57	11.33	12.34	11.84	11.95	12.89	12.42	9.16	10.04	9.6
LCNS (m)	7.61	8.47	8.04	6.49	7.01	6.75	8.83	9.87	9.35	6.64	7.45	7.05	5.86	7.22	6.54
LCEW (m)	7.32	7.92	8.62	6.24	6.65	6.44	8.38	9.1	8.74	6.3	7.3	6.8	6.06	7.37	6.71
DBH (cm)	23.64	25.51	24.58	23.07	24.74	23.9	27.52	29.64	28.58	26.74	28.77	27.75	16.53	20.04	18.29
VOL_TRUNK (m³)	0.46	0.55	0.51	0.47	0.55	0.51	0.64	0.77	0.71	0.68	0.78	0.73	0.21	0.3	0.25
D_COP (m)	7.65	8.01	7.65	6.43	6.76	6.59	8.74	9.36	9.05	6.55	7.3	6.92	6	7.25	6.63

Where: HT (tree height), HC (crown height), LCNS (crown length in the North-South direction), LCEW (East-West crown length), DBH (diameter at breast height), Vol_Trunk (trunk volume), D_Cop (crown diameter), LIC (lower limit of confidence interval) and LSC (upper limit of confidence interval)

From the dimensions or components selected in the MCA and PCA, a data set integrating these two types of synthetic variables was generated to perform the CA that allowed classifying the individuals of *A. excelsum* into five groups (Figure 1 and Table 3). In this last analysis, the 14 variables (tree descriptors) that provided information on the phenotypic variability of *A. excelsum*: RFU (stem straightness), HRAM (branching height), AIR (branch insertion angle), FCV (crown shape in vertical profile), FCH (crown shape in horizontal profile), DNC (crown density), CT (trunk color), HT (tree height), HC (crown height), LCNS (crown length in NS direction), LCEW (crown length in EW direction), DBH (diameter at breast height), Vol_trunk (trunk volume) and D_cup (canopy diameter).

In the *A. excelsum* plantation, the trees that formed groups 1 and 2 have potential for use in SSP, considering their predominant characteristics. Group 1 (11.63 %) consisted of individuals with average and intermediate values of HT, HC, DBH, trunk volume and crown diameter (Table 3); trunks with some curvatures in more than one plane, branching in the lower third and without bifurcations. Its intermediate size favors its use in SSP as dispersed trees in paddocks, at a minimum recommended planting distance of 8 m (7).

Group 2 (32.56 %) gathered individuals of intermediate size with respect to HT, HC, DBH and trunk volume, standing out for their lower DBH (Table 3), slightly twisted trunks or with some curvatures in more than one plane, branching in the lower third and without bifurcations. They could be used in SSP as live fences (7) or windbreaks (35), at a minimum recommended planting distance of 5 m (7). In group 3 (19.77 %) there were trees with greater DBH and DBH, with trunks that presented some curvatures in more than one plane, branching exclusively in the lower third and without bifurcations in most of its individuals. The potential use is timber and SSP as scattered trees in paddocks favoring shade, at a minimum planting distance of 8 m (7).

Group 4 (19.77 %) consisted of individuals with the highest mean values for HT, HC and Vol_trunk (Table 3), shafts of variable straightness (including straight), branching in the lower third and without bifurcations in most individuals.

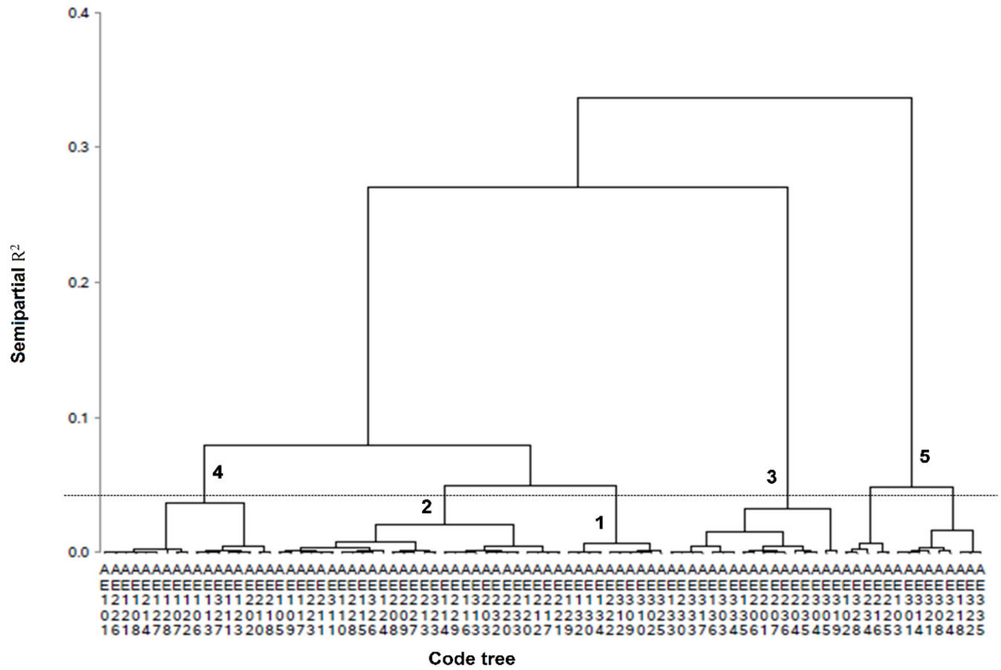

Figure 1. Dendrogram of the collection of 86 individuals of *A. excelsum*, from 14 quantitative and qualitative tree variables. Grouping by Ward method, Euclidean distance

Its potential use is mainly for timber, attributed to the greater size according to the variables HT, HC, DBH and Vol_trunk. Even the production of firewood could be considered once the logs are harvested, taking into account that this use (fuel) is reported for the species (7,8). "For the production of high quality wood and volume per individual tree, trees with more demanding qualitative characteristics of the trunk are preferred" (37), therefore, it is important to evaluate qualitative characteristics such as trunk straightness and crown shape when selecting trees for biomass production.

In group 5 (16.28 %), individuals of smaller size (HT, HC, DBH and Vol_trunk) predominated (Table 3), with slightly twisted trunks, branching in the lower third and without bifurcations. Due to the characteristics of the species and the environmental services it can provide, its potential use could be oriented to the protection of water sources and soil conservation (7), ornamental, recovery of soils and/or degraded areas (36).

CONCLUSIONS AND RECOMMENDATIONS

In the *A. excelsum* plantation of the Nataima Research Center of AGROSAVIA, 14 quantitative and qualitative tree descriptors were identified (stem and crown) that provided more information on the phenotypic variability of the species. These descriptors were useful to identify in the different clusters obtained, trees with potential for timber use and trees for silvopastoral systems under live fence arrangements and trees dispersed in plots.

To identify outstanding individuals in genetic improvement programs of *A. excelsum*, it is important to determine the parents, establish genetic tests (progeny and provenance), and evaluate the heritability of the most relevant characters in biomass production, silvopastoral systems, high quality wood, and even the genotype-by-environment interaction. In this regard, the descriptors crown height, stem straightness, trunk volume and crown size used in the study are part of the characters evaluated for the selection and incorporation of plus trees in forest genetic breeding programs.

To implement *ex situ* conservation strategies for *A. excelsum*, whose conservation status is near threatened, it is essential to identify and evaluate populations, monitor the sources of plant material and define the conservation strategy, including the evaluation of crown architecture, reproductive potential and foliar and wood functional traits. A first approach of the study was the use of the descriptors tree height and leaf area, which are some of the functional traits related to the response to environmental variability.

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