



Altitudinal Variations in Leaf Functional Traits of some Woody Species in the Savannahs of Ngaoundere (Adamaoua, Cameroon)

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Abstract

In order to contribute to the sustainable management of the Ngaoundere savannahs, experiments in natural environments were carried out to assess interspecific and altitudinal variations in leaf functional traits. To do this, 20 leaves per plant were collected from 7 individuals per species, giving a total of 140 leaves per species for each of the three sites (Dang, Tchabbal and the Cliff) in the Ngaoundere Cameroon savannahs. The leaves were photographed and the images were processed using image j software to estimate leaf area. The data obtained related to certain traits such as dry mass, leaf area, thickness, leaf specific area, specific mass, dry matter content and leaf density. For each of the three sites, dry mass decreased significantly with increasing altitude, from 1.12 g at the Dang site to 0.68 g at the Cliff site. Overall, the water content is higher at the Cliff (47.33%) and lower at Tchabbal (41.93%). Thickness increases with altitude, rising from 0.20 mm at low altitudes (Dang) to 0.30 mm at high altitudes (at the Cliff) and intermediate (0.25 mm) at medium altitudes (Tchabbal). Leaf area decreased significantly with increasing altitude, from 70.45 cm² at low altitudes (Dang) to 53.05 cm² at high altitudes (at the Cliff) and intermediate (57.70 cm²) at medium altitudes (Tchabbal). The leaf specific area decreases significantly with altitude, from 115.95 cm²/g at the Dang site to 78.16 cm²/g at the Cliff. Dry matter content increased with altitude, rising from 0.30 g/g at Dang to 0.58 g/g at the Cliff. Specific mass increased with altitude, rising from 0.00 g/cm² at Dang to 0.02 g/cm² at the Cliff. Leaf density increased with altitude, from Dang (0.06 g/mm³) to the Cliff (0.10 g/mm³). Finally, the height of the woody plants decreased with altitude, from 5.08 m at Dang to 3.80 m at the Cliff. Overall, leaf traits decreased with altitude, except for thickness and density. These results would thus contribute to an understanding of the functioning of savannah ecosystems in general, and those of Ngaoundere in particular, with a view to their sustainable management.

Keywords: Functional Trait; Altitude; Savannah; Ngaoundere; Adamaoua; Cameroon

Introduction

Savannas are vast heterogeneous complexes covering about 20 to 30 % of the earth's surface [1], where the ratio of woody to herbaceous densities varies according to climate, soil type and human pressure [2,3]. These vast areas play a major role in the socio-economic life of local populations, providing them with food and water, firewood, timber, energy, medicines, etc. They also provide many other ecosystem services, such as water supply and sanitation. They also provide many other ecosystem services to mankind by regulating the climate, the water cycle, the air, erosion, and as a place for recreation and tourism. However, at present, anthropogenic pressures and climatic hazards, through bush fires, poor agricultural practices, overgrazing, and anarchic felling of wood, due to demographic growth, and the increase in temperature and decrease in terrestrial rainfall, are leading to a degradation of forest ecosystems, particularly savannah ecosystems [4,5]. This degradation can be seen in the fragmentation of savannah formations, the reduction in biodiversity, the depletion of soil organic matter and mineral elements, biological productivity and the release of carbon into the atmosphere [6,7]. They also affect ecosystem functioning, which in fact includes the ecosystem services on which humans depend for their survival. The savannahs of Adamaoua-Cameroon, and in particular those of Ngaoundere, like other savannahs around the world, are not spared the human pressures that are leading to their degradation. Their population is expected to grow from 884.289 in 2005 to 1.308.866 in 2010. This population growth, combined with climate change, is leading to overgrazing, an increase in extensive farming practices and the exploitation of forest products, and uncontrolled urbanisation of more than 38.80% [7-10].

This situation, which has prevailed for many years in the midst of general indifference, is currently provoking numerous reactions [11], particularly from the scientific community, which agrees on the urgency of the measures to be taken to coordinate the exploitation of savannahs and develop a policy for the sustainable management of these ecosystems [12,13], in order to avoid disturbances to their functioning. Ecosystem functioning, which is the set of biotic and abiotic properties and/or processes within ecosystems, such as the recycling of organic matter and nutrients or the production of biomass, is determined through functional diversity, which represents the range and distribution of functional trait values in the community [14]. These traits exhibit intra- and interspecific and environmental variations [15,16].

Functional traits, which may be categorical (e.g. reproductive type) or continuous (e.g. size), are morphological, biochemical, physiological, structural,

phenological or behavioural characteristics expressed as phenotypes that can be measured at the scale of the individual, from the cell to the whole organism, without reference to the environment or any other level of organisation [17]. The study of biological traits is a complementary approach to taxonomic classification, making it possible to interpret the effects of human disturbance [18]. It enables us to understand how ecosystems function, as well as the adaptive strategies and responses of species to these pressures. During secondary succession, species are replaced [19], and this is often explained in terms of species adapting to changing light environments [20]. However, it is these adaptive strategies that ensure the maintenance of the species in addition to conservation actions. In addition, the term functional trait is used in many disciplines of biology such as quantitative genetics, physiology, functional ecology, demography and evolutionary biology to measure the performance of organisms [17,21-24] and it can also be used to explain many ecological processes such as photosynthesis, herbivory, etc [20].

The majority of studies on functional traits focus on herbaceous plants, as all compartments are easily accessible [25-27]. To the best of our knowledge, very few studies in this field, which has been successful in Europe or West Africa [28-32] have been carried out on plant traits and the links between foliar traits of woody species in the savannas of Adamaoua, Cameroon, with the exception of Mapongmetsem [33], who studied the interspecific variation in foliar traits of a few woody species in the Sudano-Guinean savannas of Ngaoundere. A better understanding of the functional traits and their variations would make it possible to understand the functional relationships between these plant species and their adaptation strategies in order to improve their conservation and the restoration programmes for these environments, which are constantly being disturbed. The aim of this study is to assess the environmental variation in the leaf traits of a number of woody species at three sites in the savannas of Ngaoundere 3, in order to contribute to the conservation of their biodiversity and the restoration of this ecosystem.

Methodology

Presentation of the Study Area

The study sites (Figure 1) are located in the Adamaoua region of Cameroon (6 - 8°N and 10 - 16°E), which covers an area of approximately 7200 km² and is largely made up of a vast plateau with an average altitude of 1200 m, with peaks sometimes reaching 1800 m. The study area is very rugged with numerous rivers and streams.

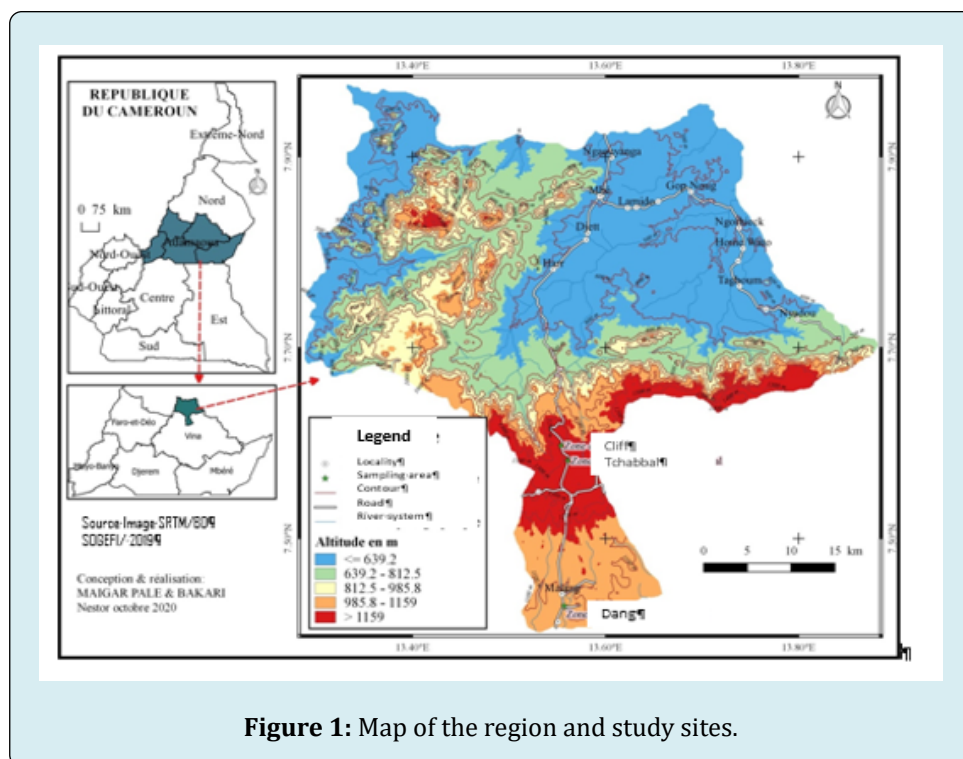


Figure 1: Map of the region and study sites.

	Altitude (m)	Disturbance	Soil	Vegetation
Dang	1060	Pastoral activities; Crops	Acidic sandy-clay Nyasiri [34]	Presence of numerous target plant species; shrub and grass savannahs, forest galleries [35]
Tchabbal	1300	Pastoral activities ; Crops	Clayey and slightly lateritic at the surface [34,36]	Absence or scarcity of some target plant species; shrub savannahs and gallery forests
Cliff	1600	Pastoral activities leading to an absence of crops and strong pressure on vegetation [37]	Covered with many stones on its surface Young and not very thick [36]	Highly heterogeneous environment [34] Savannah trees, shrubs and forest galleries [34]

Table 1: Characteristics of the study sites.

Choice of Species

Twelve (12) socio-economically important species of the Sudano-Guinean savannahs of Ngaoundere Tchobala [35] were selected. They are *Annona senegalensis* (Annonaceae), *Croton macrostachyus* (Euphorbiaceae), *Ficus sycomorus* and *Ficus thonningii* (Moraceae), *Harungana madagascariensis* (Clusiaceae), *Hymenocardia acida* (Hymenocardiaceae), *Piliostigma thonningii* (Caesalpiniaceae), *Psorospermum febrifigum* (Clusiaceae), *Syzgium guineense var. guineense* (Myrtaceae), *Terminalia glaucescens* (Combretaceae), *Vitellaria paradoxa* (Sapotaceae), and *Ximenia americana* (Olacaceae). These are contrasting species comprising trees and shrubs, with evergreen and deciduous leaves. They were

found in savannahs, forest galleries and cultivated areas or plantations. All individuals whose height was greater than or equal to 8 metres were considered to be trees Arbonnier [38] and the other individuals whose heights were below this value were considered to be shrubs. These species were chosen because they are a source of food for people and livestock, a source of income for farmers [39], an indicator of soil fertility Ibrahimia [40,41] and are threatened by human activities [7].

Choice of organ to be sampled

The study focuses on the leaves of ligneous trees rather than other plant organs because leaves are easily measurable

and, according to Garnier and Navas [42], have closer links with the ecosystem and its functioning. The impact on trees after harvesting is not significant, because the number of leaves removed is very small compared with the total foliage. These leaves are all simple.

Effect of Sites (Environmental Effect) on Leaf Traits

To estimate leaf traits, seven mature, healthy individuals of each of the 12 species were randomly selected from three habitats (savannah, forest gallery and cultivated areas or plantations) in February 2018. A transect 50 metres wide and 500 metres long was used so that the savannah and gallery could meet. The leaf collection method recommended by Cornelissen [43] was adopted. This consisted of collecting at least ten (10) leaves per plant in a well-ventilated or sun-exposed environment. The plants selected must be mature, robust and show no signs of disease. These leaves should also be taken from all compartments of the canopy in a North-South-East-West direction, preferably 2 - 3 hours after sunrise or 3 - 4 hours before sunset. On each of the seven (07) individuals in our study, twenty (20) mature, healthy and unaltered leaves were taken at random from the four (04) cardinal points (North, South, East and West) and from the centre of the canopy, in the morning before sunrise to maintain turgidity. The experimental design was a split-plot with 7 replications. The main treatment consists of the species, the secondary treatment consists of the study sites, the replication consists of the individuals and the experimental unit consists of the leaves. A total of 5040 (12 species \times 3 sites \times 7 individuals \times 20 leaves) were sampled.

Determining the Physical Characteristics of the Leaves

All samples of healthy and damaged leaves, stored in slightly damp, hermetically sealed plastic bags, were transported to the laboratory immediately after harvesting. After photographs had been taken (Figure 5) and the fresh mass determined by weighing with a balance, the leaf samples were placed in a Memmert oven at 60°C for at least 48 hours until a constant dry mass was obtained. The fresh mass (FF) and dry mass (DM) of the leaves were determined by weighing with a precision balance before and after oven drying. Leaf area (S) was estimated on fresh leaves using the digital imaging method (Image j). Leaf thickness (E) was determined between the veins of each leaf using an electronic caliper. Leaf length (LO) and width (LA) were determined using a graduated ruler. The water content (TE), leaf Specific area (SS), density (DE), specific mass or sclerophyll index (MSF) and dry matter content (TMS) were calculated using

the following formulae:

$$TE (\%) = ((MF-MS)/MS) \times 100;$$

$$SS (\text{cm}^2 / \text{g}) = S/MS;$$

$$DE (\text{g}/\text{mm}^3) = MS/S \times E;$$

$$MSF (\text{g}/\text{cm}^2) = MS/S$$

$$TMS (\text{g} \cdot \text{g}^{-1}) = MS/MF.$$

Where TE is water content (%), SS, leaf specific area (cm^2 / g), DE, density (g / mm^3), MSF, specific mass (g/cm^2), MF, fresh mass (g), MS, dry mass (g), S, leaf area (cm^2), E, leaf thickness and TMS, leaf dry matter content (g/g).

Data Analysis

The data obtained were stored and processed using Excel spreadsheets. Two-factor analyses of variance were used to determine the effect of interaction between species, and between species and the different sites. All these tests were carried out using Statgraphic 5.0 software.

Results

Variation of Leaf Length

The leaf length of the 12 woody plants in the Ngaoundere savannahs varied significantly ($P < 0.05$) between the study sites depending on the species (Table 2). Overall, with a mean of 12.21 cm, leaf length was longest in *H. madagascariensis* (17.09 cm), shortest in *H. acida* (5.86 cm) and intermediate in the other species.

For each of the three sites, leaf length is highest in *H. madagascariensis* (21.23 cm) and lowest in *H. acida* (6.42 cm) at the Dang site; it is highest in *T. glaucescens* (17.50 cm) and *V. paradoxa* (17.23 cm) and lowest in *H. acida* (5.96 cm) and *X. americana* (6.48 cm) at Tchabbal, and highest in *H. madagascariensis* (14.71 cm) and *T. glaucescens* (14.89 cm) and lowest in *X. americana* (4.60 cm) at Cliff.

Leaf length varied significantly ($P < 0.001$) between sites (Table 5). It decreased with increasing altitude, from 13.82 cm at the Dang site to 10.73 cm at the Cliff site. The Tchabbal site is in an intermediate position with a value of 12.07 cm. For each of the 12 species, leaf length is highest at Dang (lowest site) and lowest at the Cliff (highest site), with intermediate values for the Tchabbal site, except for *T. glaucescens*, whose length does not differ between Dang and Tchabbal, and for *F. sycomorus*, *P. febrifugum* and *S. guineense* var. *guineense*, whose length does not differ between Tchabbal and the Cliff. The interaction between sites and species was significant (Table 3), with $F = 28.88$ and $P < 0.001$.

Species	Dang	Tchabbal	Cliff	Average	F
AS	13.43± 1.97 e γ	12.11± 3.22 de β	10.2± 2.22 d α	11.91±2.85 E	57.62***
CM	16.22± 2.35 g γ	14.87± 2.29 f β	12.65±2.96 g α	14.58± 2.94 G	69.43***
HM	21.23± 2.90 j β	15.34± 2.35 f α	14.71± 2.93 f α	17.09± 4.01 I	239.98***
FS	13.54± 2.48 e β	12.45± 2.34 e α	12.40± 2.25 fg α	12.79± 2.41 F	10.37***
FT	11.63± 2.53 d γ	10.6± 2.99 c β	8.78± 1.82 c α	10.34± 2.75 D	46.62***
HA	6.42± 1.28 a γ	5.96± 0.97 a β	5.19± 0.79 b α	5.86± 1.15 A	50.12***
PT	14.71± 2.62 f β	12.37± 2.95 e α	11.91± 1.77 f α	13.00± 2.77 F	50.53***
PF	9.14± 1.81 b β	8.32± 1.52 b α	8.27± 1.75 c α	8.58± 1.74 C	11.48***
SG	13.08± 1.90 e β	11.6± 1.41 d α	11.24± 1.78 e α	11.97± 1.88 E	45.60***
TG	17.76± 3.04 h β	17.50± 2.50 g β	14.89± 2.50 f α	16.72± 2.98 H	48.43***
VP	18.35± 4.11 i γ	17.23± 2.64 g β	13.92± 3.28 e α	16.50± 3.88 H	64.31***
XA	10.35± 1.96 c γ	6.48± 1.82 a β	4.60± 1.26 a α	7.14± 2.94 B	41.57***
Average	13.82± 4.71 C	12.07± 4.71 B	10.73± 3.96 A	12.21± 4.53	
F	385.50***	368.45***	333.71***		

Numbers followed by different Arabic letters (a, b, c, d, e, f, g, h) in columns, different Greek letters (α, β and γ) and capital Arabic letters (A, B, C,) in rows (means), are significantly different at *** P< 0.001.

AS= *Annona senegalensis*; **CM**= *Croton macrostachyus*; **HM** = *Harungana madagascariensis*; **FS** = *Ficus sur*; **FT** = *Ficus thonningii*; **HA** = *Hymenocardia acida*; **PT** = *Piliostigma thonningii*, **PF** = *Psorospermum febrifugum*; **SG**= *Syzygium guineense* var. *guineense*; **TG** = *Terminalia glaucescens*; **VP**= *Vitellaria paradoxa*; **XA**= *Ximenia Americana*.

Table 2: Interspecific and inter-site variation in leaf Length (cm).

Source	SC	DL	MC	F
Species	63852.7	11	5804.79	1036.15***
Sites	8070.84	2	4035.42	720.32***
Species × sites	3559.09	22	161.77	28.88***

Sum of squared differences (SC), Degree of freedom (DL), Mean of squared differences (MC), significant difference at *** P < 0.001.

Table 3: Two-factor analysis of variance (species and sites) for leaf length.

Variation of Leaf Width

Leaf width of the 12 woody plants varied significantly between species and sites (Table 4). Broadly speaking, with an overall mean of 6.91 cm, leaf width was highest in *P. thonningii* (13.25 cm), lowest in *H. acida* (2.85 cm) and the other species were intermediate. For each of the three sites, leaf width varied significantly between species (Table 4). It was highest in *P. thonningii*, with values of 13.55 cm, 13.27 cm and 12.86 cm respectively for Dang, Tchabbal and cliff; the lowest value was observed in *H. acida*, with values of 2.75 cm, 3.27 cm and 2.53 cm respectively for Dang, Tchabbal and the Cliff. The other species had intermediate values for each of the three sites.

Leaf width varied significantly (P<0.001) between study sites (Table 7). It decreased with increasing altitude, from 7.40 cm at Dang to 6.57 cm at the Cliff, but this value at Dang (7.40 cm) was significantly higher than those observed at Tchabbal (6.75 cm) and at the Cliff (6.57 cm), which did not differ significantly between the latter two sites. For all 12 species, there was no clear trend in leaf width variation between sites. However, for *C. macrostachyus*; *H. madagascariensis* and *V. paradoxa*, leaf width decreased from the Dang site to the Cliff site. For *A. senegalensis*, *F. thonningii*, *P. febrifugum* and *S. guineense* var. *guineense*, the value of leaf width at Dang is greater than at the other two sites (Tchabbal and at Cliff), which do not differ significantly. Finally, for *P. thonningii*, Dang and Tchabbal do not differ from each

other and their values are higher than those of the Cliff. The interaction between sites and species is also significant

(Table 5), with $F = 33.66$ and $P < 0.001$.

Species	Dang	Tchabbal	Cliff	Average	F
AS	7.12± 1.46 β e	6.52± 2.29 α d	6.68± 1.33 α e	6.77± 1.75 G	4.36*
CM	12.71± 2.29 γ g	11.80± 2.02 β g	9.85± 2.41 α h	11.46± 2.54 K	59.17***
HM	9.87± 1.59 γ f	8.15± 1.42 β f	7.50± 1.70 α g	8.51± 1.86 J	84.65***
FS	7.73± 1.64 β e	4.95± 1.63 α b	9.86± 2.17 γ h	8.11± 2.25 I	106.63***
FT	6.27± 1.55 β d	4.95± 1.49 α b	4.97± 0.99 α c	5.40± 1.50 E	42.23***
HA	2.75± 0.45 β a	3.27± 0.57 γ a	2.53± 0.52 α a	2.85± 0.60 A	74.46***
PT	13.55± 1.88 β h	13.32± 2.64 α β h	12.86± 2.45 α i	13.25± 2.36 L	3.13*
PF	4.42± 1.10 α b	4.83± 1.03 β b	4.67± 1.36 α β c	4.64± 1.18 D	4.25*
SG	6.85± 0.92 β d	5.86± 4.28 α c	6.08± 1.29 α d	6.26± 2.66 F	5.41**
TG	7.43± 1.72 γ e	7.99± 1.22 β e	7.07± 1.55 α f	7.50± 1.55 H	13.21***
VP	4.79± 0.82 γ b	4.59± 0.64 β b	3.57± 0.98 α b	4.32± 0.98 C	86.86***
XA	5.31± 1.31 γ c	3.01± 0.48 α a	3.21± 0.47 β b	3.84± 1.34 B	309.73***
Average	7.40± 3.43 B	6.75± 3.60 A	6.57± 3.35 A	6.91± 3.48	
F	247.46***	374.06***	541.19***		

Numbers followed by different Arabic letters (a, b, c, d, e, f, g, h) in columns, different Greek letters (α, β and γ) and capital Arabic letters (A, B, C,) in rows (means), are significantly different at *** $P < 0.001$.

AS= *Annona senegalensis*; **CM**= *Croton macrostachyus*; **HM** = *Harungana madagascariensis*; **FS** = *Ficus sur*; **FT** = *Ficus thonningii*; **HA** = *Hymenocardia acida*; **PT** = *Piliostigma thonningii*, **PF** = *Psorospermum febrifugum*; **SG**= *Syzygium guineense* var. *guineense*; **TG** = *Terminalia glaucescens*; **VP**= *Vitellaria paradoxa*; **XA**= *Ximenia Americana*.

Table 4: Interspecific and inter-site variation in leaf width (cm).

Source	SC	DL	MC	F
Species	44372.6	11	4033.87	1434.43***
Sites	640.08	2	113.81	113.81***
Species × sites	2082.57	22	33.66	33.66***

Sum of squared differences (SC), Degree of freedom (DL), Mean of squared differences (MC), significant difference at ***: $P < 0.001$.

Table 5: Two-factor (species and site) analysis of variance for leaf width.

Variation of Leaf Fresh Mass

The fresh mass of the leaves of the 12 woody plants varied significantly between species and sites (Table 6). With an overall mean value of 1.87 g, leaf fresh mass was highest in *P. thonningii* (4.92 g) and lowest in *H. acida* (0.29 g), with the other species showing intermediate values. For each of the three sites, the fresh mass of the leaves varied significantly between species (Table 6). It was highest in *P. thonningii* at all sites, with values of 5.39 g, 5.24 g and 4.14 g respectively for Dang, Tchabbal and the Cliff; the lowest value was observed in *H. acida*, with values of 0.37 g, 0.27 g and 0.22 g respectively for Dang, Tchabbal and the Cliff, but also in *X. americana* (0.21g) at the Cliff. The other species showed

intermediate values for each of the three sites.

Fresh leaf mass varied significantly between sites ($P < 0.001$) (Table 6). Overall, it decreased significantly ($P < 0.01$) with increasing altitude, from 2.37 g at the Dang site to 1.46 g at the Cliff site. Tchabbal is in an intermediate position with a value of 1.78 g. For *A. senegalensis*, *C. macrostachyus*, *H. acida*, *T. glaucescens* and *Ximenia americana* the fresh mass of the leaves is highest at Dang and lowest at the Cliff, with intermediate values for the Tchabbal site. For *H. madagascariensis*, *F. sur*, *F. thonningii* and *S. guineense* var. *guineense*, the value for fresh leaf mass at Dang was higher than at the other sites (Tchabbal and Cliff), which did not differ significantly. On the other hand, for *P. thonningii*, *P.*

febrifugum and *V. paradoxa*, the fresh mass value of leaves from Dang and Tchabbal, which do not differ from each other, is significantly higher than those from the Cliff. The

interaction between sites and species is significant (Table 7), with an F value of 24.80 and $P < 0.001$.

Species	Dang	Tchabbal	Cliff	Average	F
AS	3.57±1.39 γ f	1.90±0.70 β d	1.49±0.82 α de	2.32± 1.36 G	162.74***
CM	3.37±0.92 γ e	3.11±1.09 β f	2.36±0.88 α f	2.95± 1.05 H	40.01***
HM	4.15±1.20 β g	2.55±1.00 α e	2.34±1.47 α f	3.01±1.48 H	89.20***
FS	1.92±0.67 β d	1.33±0.99 α c	1.16±0.62 α c	1.47±0.84 E	36.42***
FT	1.71±0.97 β d	0.87±0.49 α b	0.77±0.36 α b	1.11±0.78 D	84.48***
HA	0.37±0.14 γ a	0.27±0.07 β a	0.22±0.05 α a	0.29±0.11 A	85.18***
PT	5.39±1.84 β h	5.24±1.66 β g	4.14±1.56 α g	4.92±1.78 I	22.74***
PF	0.84±0.59 β b	0.80±0.47 β b	0.68±0.28 α b	0.77±0.47 C	4.70***
SG	1.82±0.58 β d	1.39±0.37 α c	1.32±0.36 α cd	1.51±0.50 E	51.09***
TG	2.14±0.70 γ d	1.90±0.64 β d	1.63±0.94 α e	1.89±0.79 F	19.49***
VP	1.78±0.64 β d	1.74±0.86 β d	1.18±0.57 α c	1.57±0.75 E	31.34***
XA	1.41±0.67 γ c	0.31±0.14 β a	0.21±0.14 α a	0.64±0.67 B	370.52***
Average	2.37± 1.69 C	1.78±1.55 B	1.46±1.32 A	1,87±1.58	
F	319.09***	386.27***	248.24***		

Numbers followed by different Arabic letters (a, b, c, d, e, f, g, h) in columns, different Greek letters (α , β and γ) and capital Arabic letters (A, B, C,) in rows (means), are significantly different at *** $P < 0.001$.

AS= *Annona senegalensis*; **CM**= *Croton macrostachyus*; **HM** = *Harungana madagascariensis*; **FS** = *Ficus sur*; **FT** = *Ficus thonningii*; **HA** = *Hymenocardia acida*; **PT** = *Piliostigma thonningii*, **PF** = *Psorospermum febrifugum*; **SG**= *Syzygium guineense* var. *guineense*; **TG** = *Terminalia glaucescens*; **VP**= *Vitellaria paradoxa*; **XA**= *Ximenia Americana*.

Table 6: Interspecific and inter-site variation in fresh leaf mass (g).

Source	SC	DL	MC	F
Species	7623.13	11	693.01	905.82***
Sites	722.81	2	361.40	472.39***
Species × sites	417.38	22	18.97	24.80***

Sum of squared differences (SC), Degree of freedom (DL), Mean of squared differences (MC), significant difference at ***: $P < 0.001$.

Table 7: Analysis of fresh mass variance between species and sites.

Variation of Leaf Dry Mass

Leaf dry mass of the 12 woody species varied significantly ($P < 0.001$) between species and between study sites (Table 8). With an overall mean value of 0.88 g, leaf dry mass was highest in *P. thonningii* (2.02 g), lowest in *H. acida* (0.19 g) and intermediate in the other species. In each of the three sites, leaf dry mass varied significantly between species (Table 8). It was highest for *P. thonningii* at all sites, with values of 2.32 g, 1.91 g and 1.84 g respectively for Dang, Tchabbal and the Cliff; the lowest value was observed for *H. acida*, with values of 0.24 g, 0.17 g and 0.16 g respectively for Dang, Tchabbal and the Cliff, but also for *X. americana* at

Tchabbal (0.22 g) and at the Cliff (0.18 g). The other species had intermediate values at each of the three sites. Leaf dry mass varied significantly between sites ($P < 0.001$) (Table 8). Overall, it decreased significantly ($P < 0.01$) with increasing altitude, from 1.12 g at the Dang site to 0.68 g at the Cliff site. Tchabbal is in an intermediate position with a value of 0.85 g. For *C. macrostachyus*, *H. madagascariensis*, *T. glaucescens* and *X. americana*, leaf dry mass is highest at Dang and lowest at the Cliff, with intermediate values for the Tchabbal site. For *A. senegalensis*, *F. sur*, *H. acida* and *P. thonningii*, the leaf dry mass value at Dang is higher than those at the other sites (Tchabbal and Cliff), which do not differ significantly. On the other hand, for *F. thonningii*, *P. febrifugum* and *S. guineense*

var. *guineense*, the leaf dry mass values for Dang and Tchabbal, which do not differ from each other, are significantly higher

than those for Cliff. The interaction between sites and species is significant (Table 9), with $F = 25.87$ and $P < 0.001$.

Species	Dang	Tchabbal	Cliff	Average	F
AS	1.73±0.61 β g	1.01±0.50 α e	1.00±0.41 α e	1.25±0.61 G	90.49***
CM	1.44±0.40 γ f	1.22±0.45 β f	0.93±0.26 α e	1.20±0.43 FG	62.21***
HM	1.63±0.48 γ g	1.00±0.34 β e	0.48±0.32 α c	1.04±0.61 E	301.82***
FS	1.09±0.58 β e	0.71±0.38 α c	0.70±0.36 α d	0.83±0.49 D	33.33***
FT	0.48±0.25 β b	0.44±0.14 β b	0.36±0.20 α b	0.43±0.21 C	11.71***
HA	0.24±0.7 β a	0.17±0.07 α a	0.16±0.04 α a	0.19±0.07 A	61.61***
PT	2.32±0.77 β h	1.91±0.59 α g	1.84±0.94 α f	2.02±0.81 H	15.07***
PF	0.55±0.29 β b	0.49±0.24 β b	0.37±0.16 α b	0.47±0.25 C	20.28***
SG	0.91±0.24 β d	0.91±0.27 β d	0.70±0.16 α d	0.84±0.25 D	38.98***
TG	1.44±0.44 γ f	1.18±0.41 β f	0.96±0.37 α e	1.19±0.45 F	47.90***
VP	0.98±0.54 β d	0.93±0.25 β de	0.50±0.21 α c	0.80±0.42 D	71.03***
XA	0.67±0.27 γ c	0.22±0.11 β a	0.18±0.06 α a	0.36±0.28 B	341.36***
Average	1.12±0.73 C	0.85±0.58 B	0.68±0.58 A	0.88±0.66	
F	247.46***	264.91***	217.95***		

Numbers followed by different Arabic letters (a, b, c, d, e, f, g, h) in columns, different Greek letters (α, β and γ) and capital Arabic letters (A, B, C,) in rows (means), are significantly different at *** $P < 0.001$.

AS= *Annona senegalensis*; **CM**= *Croton macrostachyus*; **HM** = *Harungana madagascariensis*; **FS** = *Ficus sur*; **FT** = *Ficus thonningii*; **HA** = *Hymenocardia acida*; **PT** = *Piliostigma thonningii*, **PF** = *Psorospermum febrifugum*; **SG**= *Syzygium guineense* var. *guineense*; **TG** = *Terminalia glaucescens*; **VP**= *Vitellaria paradoxa*; **XA**= *Ximenia Americana*.

Table 8: Interspecific and inter-site variation in leaf dry mass (g).

Source	SC	DL	MC	F
Species	1174.05	11	106.73	678.32***
Sites	166.37	2	83.18	528.69***
Species × sites	89.53	22	4.06	25.87***

Sum of squared differences (SC), Degree of freedom (DL), Mean of squared differences (MC), significant difference at : *** : $P < 0.001$.

Table 9: Analysis of variance with two factors (species and sites) concerning dry mass.

Variation of Moisture Content

Table 10 shows the interspecific and intersite variations in leaf water content for the 12 woody species surveyed. This moisture content varies significantly ($P < 0.001$) between sites and between species, except in the case of *C. macrostachyus* and *F. sur*. With an overall mean value of 44.85%, leaf water content was highest in *H. madagascariensis* (73.99%), lowest in *H. acida* (23.91%) and intermediate in the other species.

In each of the three sites, leaf water content varied significantly ($P < 0.001$) between species (Table 10). It was highest in *F. thonningii* (88.48%), *H. madagascariensis*

(71.31%) and *H. madagascariensis* (92.26%) at Dang, Tchabbal and at the Cliff respectively. The lowest values were observed for *T. glaucescens* (21.81%) and *H. acida* (22.52%) at the Dang site, for *S. guineense* var. *guineense* (21.69%), *X. americana* (23.60%) and *H. acida* (25.39%) at the Tchabbal site and for *X. americana* (15.07%) and *H. acida* (23.82%) at the Cliff site. The other species showed intermediate values for each of the three sites.

Leaf water content varied significantly ($P < 0.001$) between sites, except for *C. macrostachyus* and *F. sur* (Table 13). Overall, it was highest at the Cliff (47.33%), lowest at Tchabbal (41.93%) and intermediate at Dang (45.31%). No

clear trend emerged for any of the 12 woody species studied. Variation in leaf water content between sites is influenced

by species. The interaction between sites and species is significant (Table 11), with an F value of 23.76 and $P < 0.001$.

Species	Dang	Tchabbal	Cliff	Average	F
AS	42.97 ± 5.02αβ cd	40.40 ± 4.88 β cd	33.81 ± 4.08 α bc	39.06 ± 4.72C	4.30*
CM	50.44 ± 6.74α def	65.58 ± 8.76 β e	62.16 ± 8.30αβ d	59.39 ± 7.94 ^E	2.51ns
HM	58.42 ± 13.47α f	71.31 ± 16.45 α e	92.26 ± 21.28 β e	73.99 ± 17.07G	46.01***
FS	38.06 ± 4.91α bc	46.74 ± 6.03 α d	37.28 ± 4.81 α c	40.69 ± 5.25CD	1.53ns
FT	88.48 ± 36.32 γ g	37.59 ± 15.43 α bcd	60.22 ± 24.72 β d	62.09 ± 25.49F	33.57***
HA	22.52 ± 1.34β a	25.39 ± 1.51 β a	23.82 ± 1.42 α ab	23.91 ± 1.43 A	5.75*
PT	52.85 ± 9.02α ef	74.25 ± 12.85 β e	61.69 ± 10.53αβ d	62.93 ± 10.75 ^E	3.05 *
PF	27.96 ± 5.38 α ab	38.35 ± 7.38 β bcd	41.02 ± 7.90 β c	35.77 ± 6.89BC	2.05*
SG	39.44 ± 11.69β bcd	21.69 ± 6.43α a	37.74 ± 11.18 β c	32.95 ± 9.79 BC	14.48***
TG	21.81 ± 5.63 α a	28.39 ± 7.34 αβ ab	36.78 ± 9.51 β c	28.99 ± 7.50 B	2.80*
VP	45.49 ± 17.50α cde	29.95 ± 11.53 α abc	66.22 ± 25.48 β d	47.22 ± 18.19D	11.27***
XA	55.37 ± 37.50 β ef	23.60 ± 15.98 α a	15.07 ± 12.19 α a	31.34 ± 21.23 B	26.65***
Average	45.31 ± 18.30 B	41.93 ± 18.75 A	47.33 ± 21.50 C	44.85 ± 20.37	
F	29.76***	13.61***	48.79***		

Numbers followed by different Arabic letters (a. b. c. d. e. f. g. h) in columns, different Greek letters (α. β and γ) and capital Arabic letters (A. B. C.) in rows (means), are significantly different at *** $P < 0.001$.

AS= *Annona senegalensis*; **CM**= *Croton macrostachyus*; **HM** = *Harungana madagascariensis*; **FS** = *Ficus sur*; **FT** = *Ficus thonningii*; **HA** = *Hymenocardia acida*; **PT** = *Piliostigma thonningii*. **PF** = *Psorospermum febrifugum*; **SG**= *Syzygium guineense* var. *guineense*; **TG** = *Terminalia glaucescens*; **VP**= *Vitellaria paradoxa*; **XA**= *Ximenia Americana*.

Table 10: Inter-specific and inter-site variation in leaf water content (%).

Source	SC	DL	MC	F
Species	2.16	11	1.96	58.15***
Sites	798120.00	2	399060.00	11.82***
Species × sites	1.76	22	802394.00	23.76***

Sum of squared differences (SC). Degree of freedom (DL). Mean of squared differences (MC), significant difference at : *** : $P < 0.001$

Table 11: Two-factor analyses of variance (species and sites) for leaf water content.

Variation of Leaf Thickness

Table 12 shows the leaf thickness values for the ligneous plants studied. They vary significantly ($P < 0.001$) between sites and species. With a mean value of 0.25 mm, leaf thickness was highest overall for *H. madagascariensis* (0.35 mm), lowest for *A. senegalensis* (0.19 mm) and *F. sur* (0.19 mm) and intermediate for the other species.

In each of the three sites, leaf thickness varied significantly ($P < 0.001$) between species (Table 12). It was lowest in *S. guineense* var. *guineense* (0.12 mm) and highest in *A. senegalensis* (0.32 mm) at the Dang site; it was lowest in *A. senegalensis* at the Tchabbal (0.13 mm) and at the Cliff

(0.13 mm) sites and highest in *H. acida* (0.33 mm) at the Tchabbal sites and in *H. madagascariensis* (0.55 mm) at the Cliff. The other species had intermediate values at each of the three sites.

Leaf thickness varied significantly ($P < 0.001$) between sites (Table 15). Overall, it increased with altitude, rising from 0.20 mm at low altitudes (Dang) to 0.30 mm at high altitudes (Cliff) and intermediate (0.25 mm) at medium altitudes (Tchabbal). For *C. macrostachyus*, *H. madagascariensis*, *T. glaucescens* and *X. americana*, leaf dry mass is highest at Dang and lowest at the Cliff, with intermediate values for the Tchabbal site. For *H. madagascariensis*, *S. guineense* var. *guineense* and *T. glaucescens*, the value of leaf thickness

increases with altitude from Dang to Cliff. On the other hand, for *P. thonningii*, *V. paradoxa* and *X. americana*, the leaf thickness value at Cliff is significantly higher than those at Tchabbal and Dang, which do not differ significantly from

each other. The interaction between sites and species is significant (Table 13), with an F value of 339.19 and $P < 0.001$.

Species	Dang	Tchabbal	Cliff	Average	F
AS	0.30±0.02 β i	0.13±0.02 α a	0.13±0.03 α a	0.19±0.08 A	1482.48***
CM	0.22±0.02 α f	0.30±0.03 β g	0.21±0.04 α c	0.24±0.05 D	234.70***
HM	0.18±0.04 α d	0.31±0.04 β gh	0.55±0.05 γ h	0.35±0.15 I	1871.61***
FS	0.14±0.04 α b	0.23±0.05 γ c	0.21±0.02 β c	0.19±0.05 A	188.95***
FT	0.26±0.03 α h	0.31±0.03 β h	0.31±0.03 β e	0.29±0.04 H	117.60***
HA	0.20±0.03 α e	0.33±0.05 β i	0.20±0.03 α b	0.24±0.07 D	443.15***
PT	0.23±0.02 α g	0.23±0.02 α c	0.33±0.02 β f	0.26±0.05 F	659.61***
PF	0.26±0.03 β b	0.24±0.03 α d	0.28±0.05 γ d	0.22±0.07 C	457.22***
SG	0.12±0.02 α a	0.27±0.03 β e	0.36±0.12 γ g	0.25±0.12 E	366.72***
TG	0.21±0.02 α f	0.28±0.05 β f	0.31±0.03 γ e	0.27±0.05 F	237.08***
VP	0.15±0.03 α c	0.15±0.03 α b	0.31±0.05 β e	0.20±0.08 B	678.46***
XA	0.25±0.03 α h	0.23±0.03 α cd	0.36±0.15 β g	0.28±0.10 G	96.26***
Average	0.20±0.06 A	0.25±0.07 B	0.30±0.12 C	0.25±0.09	
F	418.73***	351.60***	328.86***		

Numbers followed by different Arabic letters (a. b. c. d. e. f. g. h) in columns, different Greek letters (α. β and γ) and capital Arabic letters (A. B. C.) in rows (means), are significantly different at *** $P < 0.001$.

AS= *Annona senegalensis*; **CM**= *Croton macrostachyus*; **HM** = *Harungana madagascariensis*; **FS** = *Ficus sur*; **FT** = *Ficus thonningii*; **HA** = *Hymenocardia acida*; **PT** = *Piliostigma thonningii*. **PF** = *Psorospermum febrifugum*; **SG**= *Syzygium guineense* var. *guineense*; **TG** = *Terminalia glaucescens*; **VP**= *Vitellaria paradoxa*; **XA**= *Ximenia Americana*.

Table 12: Interspecific and inter-site variation in leaf thickness (mm).

Source	SC	DL	MC	F
Species	9.75	11	0.88	360.27***
Sites	7.89	2	3.94	1603.02***
Species × sites	18.37	22	0.83	339.19***

Sum of squared differences (SC). Degree of freedom (DL). Mean of squared differences (MC), significant difference at : *** : $P < 0.001$

Table 13: Two-factor analyses of variance (species and sites) for leaf thickness.

Leaf Area Variation

The leaf area of the 12 species studied varied significantly ($P < 0.001$) between study sites and species (Table 14). With an overall mean value of 60.40 cm², leaf area was highest in *P. thonningii* (13.30 cm²), lowest in *X. americana* (10.36 cm²) and *H. acida* (13.30 cm²) and intermediate in the other species.

In each of the three sites, leaf area varied significantly ($P < 0.001$) between species (Table 14). Leaf area was highest in *P. thonningii* at all study sites, with values of 119.12 cm²,

117.40 cm² and 107.90 cm² at Dang, Tchabbal and at the Cliff respectively. It was lowest in *X. americana*, with values of 12.14 cm², 9.59 cm² and 9.35 cm² respectively at Dang, Tchabbal and at the Cliff, but with *H. acida* at Dang (15.31 cm²) and at the Cliff (9.46 cm²). The other species had intermediate values at each of the three sites.

Leaf area varied significantly between sites (Table 14). Overall, it decreased significantly with increasing altitude, from 70.45 cm² at low altitudes (Dang) to 53.05 cm² at high altitudes (Cliff) and intermediate (57.70 cm²) at medium altitudes (Tchabbal). For *S. guineense* var. *guineense* and

T. glaucescens, the leaf area value is significantly highest at Dang and lowest at the Cliff, with intermediate values for the Tchabbal site. For *C. macrostachyus*, *H. acida*, *P. thonningii* and *P. febrifugum*. This leaf area value at the Cliff site is significantly lower than those at Dang and Tchabbal, which do not differ significantly from each other. On the other hand,

for the rest of the species, the leaf area at Dang is significantly higher than those at Tchabbal and at the Cliff, which do not differ significantly between them. The interaction between sites and species was also significant (Table 15), with an F value of 10.31 and $P < 0.001$.

Species	Dang	Tchabbal	Cliff	Average	F
AS	87.82 ± 31.91 β e	66.05 ± 19.19 α g	62.81 ± 18.17 α f	72.22 ± 26.33 F	45.23***
CM	114.10 ± 81.38 β g	110.46 ± 20.39 β i	93.04 ± 25.40 α h	105.87 ± 51.32 I	6.92**
HM	79.41 ± 25.12 β d	67.15 ± 17.76 α g	66.55 ± 22.32 α f	71.03 ± 22.68 F	15.30***
FS	87.83 ± 50.11 β ef	54.21 ± 23.27 α f	53.03 ± 22.62 α e	65.02 ± 37.99 E	45.99***
FT	46.37 ± 31.04 β c	34.98 ± 9.74 α d	34.38 ± 13.82 α c	38.58 ± 21.09 C	15.33***
HA	15.31 ± 4.98 β a	15.15 ± 4.84 β b	9.46 ± 3.10 α a	13.30 ± 5.16 A	80.29***
PT	119.12 ± 40.35 β g	117.40 ± 50.85 β j	107.90 ± 21.77 α i	114.81 ± 39.74 J	3.27*
PF	32.25 ± 17.11 β b	29.29 ± 11.44 β c	23.10 ± 8.70 α b	28.21 ± 13.43 B	18.33***
SG	50.15 ± 12.94 γ c	43.07 ± 9.36 β e	39.95 ± 6.41 α d	44.39 ± 10.79 D	38.69***
TG	101.99 ± 30.34 γ f	77.28 ± 19.27 β h	71.42 ± 14.46 α g	83.56 ± 25.96 H	73.66***
VP	98.87 ± 23.26 β f	67.82 ± 13.87 α g	65.60 ± 17.37 α f	77.43 ± 23.97 G	140.30***
XA	12.14 ± 4.35 β a	9.59 ± 3.47 α a	9.35 ± 5.18 α a	10.36 ± 4.56 A	17.36***
Average	70.45 ± 50.74 C	57.70 ± 38.49 B	53.05 ± 34.04 A	60.40 ± 32.33	
F	155.81***	376.36***	488.53***		

Numbers followed by different Arabic letters (a. b. c. d. e. f. g. h) in columns, different Greek letters (α. β and γ) and capital Arabic letters (A. B. C.) in rows (means), are significantly different at *** $P < 0.001$.

AS= *Annona senegalensis*; **CM**= *Croton macrostachyus*; **HM** = *Harungana madagascariensis*; **FS** = *Ficus sur*; **FT** = *Ficus thonningii*; **HA** = *Hymenocardia acida*; **PT** = *Piliostigma thonningii*. **PF** = *Psorospermum febrifugum*; **SG**= *Syzygium guineense* var. *guineense*; **TG** = *Terminalia glaucescens*; **VP**= *Vitellaria paradoxa*; **XA**= *Ximenia Americana*.

Table 14: Inter-specific and inter-site variation in leaf area.

Source	SC	DL	MC	F
Species	5.29	11	481808.81	728.81***
Sites	272522.00	2	136261.00	206.12***
Species × sites	149890.00	22	6813.18	10.31***

Sum of squared differences (SC). Degree of freedom (DL). Mean of squared differences (MC), significant difference at ***: $P < 0.001$.

Table 15: Two-factor analyses of variance (species and sites) for leaf area.

Specific Leaf Area Variation

Table 16 shows the specific leaf area values for the species studied. They vary significantly ($P < 0.001$) between study sites and species, except in the case of *P. febrifugum* where there is no significant difference. With an overall mean value of 87.55 cm²/g, specific leaf area was highest in *V. paradoxa* (142.90 cm²/g), lowest in *X. americana* (44.92 cm²/g) and intermediate in the other species.

In each of the three sites, specific leaf area varied significantly ($P < 0.001$) between species (Table 16). It was highest in *V. paradoxa* (268.09 cm²/g) and lowest in *X. americana* (22.32 cm²/g) at the Dang site, highest in *F. sur* (97.37 cm²/g) and lowest in *S. guineense* var. *guineense* (52.02 cm²/g) for the Tchabbal site and the highest for *F. thonningii* (135.99 cm²/g), the lowest for *H. madagascariensis* (44.19 cm²/g) for the Cliff site. The other species had intermediate values at each of the three sites.

Specific leaf area varied significantly ($P < 0.001$) between sites (Table 16). Overall, it decreased significantly with increasing altitude, from 115.95 cm²/g for Dang to 78.16 cm²/g for Cliff, and intermediate (68.56 cm²/g) for Tchabbal. For *P. febrifugum*, the specific leaf area did not differ significantly between the three study sites. On the other hand, for *H. madagascariensis*, *F. sur*, *H. acida* and *T. glaucescens*, the value of specific leaf area is significantly highest at Dang and lowest at the Cliff, with intermediate values for the Tchabbal

site. For *C. macrostachyus*, *S. guineense* var *guineense* and *V. paradoxa*. This value of specific leaf area at Dang is significantly higher than those at Tchabbal and at the Cliff, which do not differ significantly between them. For the other species, there was no clear trend in the variation in specific leaf area between study sites. The interaction between sites and species was also significant (Table 17), with an F value of 43.02 and $P < 0.001$.

Species	Dang	Tchabbal	Cliff	Average	F
AS	56.03 ± 26.29 α b	82.16 ± 53.63 β def	74.23 ± 38.30 β c	70.20 ± 42.31 C	14.97***
CM	136.09 ± 119.70 β ef	83.94 ± 33.01 α def	86.31 ± 38.98 α d	102.11 ± 78.73 E	21.50***
HM	231.34 ± 152.70 γ g	77.34 ± 42.54 β cd	44.19 ± 20.28 α a	117.62 ± 103.03 F	164.01***
FS	149.93 ± 110.94 γ g	97.37 ± 68.89 β g	60.27 ± 42.62 α b	102.53 ± 87.27 E	45.17***
FT	117.91 ± 93.54 β de	88.77 ± 39.37 α efg	135.99 ± 96.24 β e	114.23 ± 86.84 F	11.04***
HA	94.34 ± 39.74 γ cd	68.94 ± 39.29 β bc	60.60 ± 23.82 α b	74.62 ± 37.82 CD	35.14***
PT	69.53 ± 36.31 β bc	83.11 ± 60.77 γ def	51.39 ± 19.57 α ab	68.01 ± 44.26 BC	19.1***
PF	70.04 ± 42.65 α bc	75.21 ± 45.87 α cd	72.37 ± 39.24 α c	72.56 ± 46.41 CD	0.45ns
SG	74.30 ± 22.80 β bc	52.02 ± 26.41 α a	47.48 ± 14.73 α a	57.93 ± 24.77 B	60.30***
TG	101.48 ± 60.53 γ d	91.41 ± 40.39 α fg	54.38 ± 21.32 β ab	82.42 ± 48.15 D	44.92***
VP	268.09 ± 103.93 β h	78.38 ± 28.88 α cde	82.22 ± 43.30 α cd	142.90 ± 108.51 G	51.93***
XA	22.32 ± 16.05 α a	59.19 ± 31.62 β ab	53.26 ± 33.92 β ab	44.92 ± 36.32 A	51.66***
Average	115.95 ± 104.47 C	78.16 ± 46.82 B	68.56 ± 40.26 A	87.55 ± 79.53	
F	54.14***	11.60***	45.52***		

Numbers followed by different Arabic letters (a. b. c. d. e. f. g. h) in columns, different Greek letters (α. β and γ) and capital Arabic letters (A. B. C.) in rows (means), are significantly different at *** $P < 0.001$.

AS= *Annona senegalensis*; **CM**= *Croton macrostachyus*; **HM** = *Harungana madagascariensis*; **FS** = *Ficus sur*; **FT** = *Ficus thonningii*; **HA** = *Hymenocardia acida*; **PT** = *Piliostigma thonningii*. **PF** = *Psorospermum febrifugum*; **SG**= *Syzygium guineense* var. *guineense*; **TG** = *Terminalia glaucescens*; **VP**= *Vitellaria paradoxa*; **XA**= *Ximenia Americana*.

Table 16: Interspecific and inter-site variation in specific leaf area (cm²/g).

Source	SC	DL	MC	F
Species	3.73	11	339436.00	58.46***
Sites	2.10	2	1.05	181.62***
Species × sites	5.49	22	249776.00	43.02***

Sum of squared differences (SC), Degree of freedom (DL), Mean of squared differences (MC) significant difference at ***. $P < 0.001$.

Table 17: Two-factor analyses of variance (species and sites) for specific leaf area.

Leaf Dry Matter Content Variation

The dry matter content of the 12 woody species studied varied significantly between study sites and species (Table 18), with the exception of *F. sur* and *H. acida* where the difference between sites was not significant ($P > 0.05$). With an overall mean value of 0.63 g/g, leaf dry matter content

was highest in *P. febrifugum* (0.80 g/g) and *X. americana* (0.83 g/g), lowest in *H. madagascariensis* (0.40 g/g) and intermediate in the other species.

In each of the three sites, the dry matter content varied significantly ($P < 0.001$) between species (Table 18). It was highest in *P. febrifugum* (0.85 g/g) and lowest in *C.*

macrostachyus (0.30 g/g) and *H. madagascariensis* (0.32 g/g) at the Dang site, highest in *X. americana* (1.05 g/g) and lowest in *H. madagascariensis* (0.45 g/g) at the Tchabbal site, and the highest values for *X. americana* (0.85 g/g) and *T. glaucescens* (0.87 g/g) and the lowest for *H. madagascariensis* (0.43 g/g) at the Cliff site. The other species had intermediate values for each of the three sites.

Dry matter content varied significantly ($P < 0.001$) between sites (Table 18). Overall, it was highest at Tchabbal (0.70 g/g), lowest at Dang (0.54 g/g) and intermediate at the Cliff (0.65 g/g). Sites did not differ significantly for *F.*

sur and *H. acida*. In *C. macrostachyus*, dry matter content increased with altitude, rising from 0.30 g/g at Dang to 0.58 g/g at the Cliff and intermediate at Tchabbal (0.52 g/g). In *H. madagascariensis*, *F. thonningii*, *P. thonningii*, and *V. paradoxa*, the dry matter content at Dang is significantly lower than at Tchabbal and at the Cliff, which do not differ significantly from each other. For the remaining species, there was no clear trend in the variation of dry matter content between study sites. The interaction between sites and species was also significant (Table 19), with an F value of 6.61 and $P < 0.001$.

Species	Dang	Tchabbal	Cliff	Average	F
AS	0.53 ± 0.21 α c	0.83 ± 0.56 β ef	0.62 ± 0.38 α cd	0.66 ± 0.43 DE	19.49***
CM	0.30 ± 0.13 α a	0.52 ± 0.21 β ab	0.58 ± 0.28 γ bcd	0.46 ± 0.24 B	63.55***
HM	0.32 ± 0.28 α a	0.45 ± 0.25 β a	0.43 ± 0.19 β a	0.40 ± 0.29 A	9.02***
FS	0.66 ± 0.44 α de	0.76 ± 0.59 α de	0.66 ± 0.42 α d	0.69 ± 0.56 EF	1.38ns
FT	0.38 ± 0.29 α ab	0.66 ± 0.46 β cd	0.61 ± 0.43 β bcd	0.55 ± 0.45 C	13.77***
HA	0.70 ± 0.33 α e	0.73 ± 0.33 α β de	0.78 ± 0.28 α ef	0.74 ± 0.31 F	2.14ns
PT	0.41 ± 0.23 α b	0.51 ± 0.34 β ab	0.51 ± 0.28 β ab	0.47 ± 0.29 B	5.41*
PF	0.85 ± 0.62 β f	0.87 ± 0.64 β f	0.69 ± 0.59 α de	0.80 ± 0.66 G	3.22*
SG	0.53 ± 0.17 α c	0.73 ± 0.24 β de	0.53 ± 0.21 α abc	0.60 ± 0.23 C	40.77***
TG	0.64 ± 0.47 α de	0.68 ± 0.33 α cd	0.87 ± 0.52 β f	0.73 ± 0.46 F	10.69***
VP	0.54 ± 0.42 α c	0.60 ± 0.29 α β bc	0.67 ± 0.43 β d	0.60 ± 0.39 C	4.05*
XA	0.60 ± 0.37 α cd	1.05 ± 0.61 γ g	0.85 ± 0.61 β f	0.83 ± 0.57 G	23.93***
Average	0.54 ± 0.40 A	0.70 ± 0.46 C	0.65 ± 0.48 B	0.63 ± 0.45	
F	28.12***	20.78***	11.74***		

Numbers followed by different Arabic letters (a. b. c. d. e. f. g. h) in columns, different Greek letters (α. β and γ) and capital Arabic letters (A. B. C.) in rows (means), are significantly different at *** $P < 0.001$.

AS= *Annona senegalensis*; CM= *Croton macrostachyus*; HM = *Harungana madagascariensis*; FS = *Ficus sur*; FT = *Ficus thonningii*; HA = *Hymenocardia acida*; PT = *Piliostigma thonningii*. PF = *Psorospermum febrifugum*; SG= *Syzygium guineense* var. *guineense*; TG = *Terminalia glaucescens*; VP= *Vitellaria paradoxa*; XA= *Ximenia Americana*.

Table 18: Interspecific and inter-site variation in dry matter content (g/g).

Source	SC	DL	MC	F
Species	87.65	11	7.96	43.85***
Sites	23.17	2	11.58	63.78***
Species × sites	26.43	22	1.20	6.61***

Sum of squared differences (SC). Degree of freedom (DL). Mean of squared differences (MC), significant difference at ***. $P < 0.001$.

Table 19: Analyses of variance of the two factors (species and sites) concerning dry matter content.

Specific Leaf Mass Variation

Table 20 shows the specific leaf mass of the 12 woody species studied. It varied significantly ($P < 0.001$) between

sites and species, with the exception of *C. macrostachyus*. *F. thonningii* and *P. febrifugum* where the difference between sites was not significant ($P > 0.05$). With an overall mean value of 0.01 g/cm², leaf density was highest in *X. americana*

(0.03 g/ cm²), lowest in *V. paradoxa* (0.01 g/ cm²) and intermediate in the other species.

In each of the three sites, the specific leaf mass varied significantly ($P < 0.001$) between species (Table 20). It was highest in *X. americana* at all three sites, with values of 0.06 g/ cm². 0.02 g/ cm² and 0.03 g/ cm² at Dang, Tchabbal and at the Cliff respectively, and in *S. guineense* var. *guineense* (0.02 g/ cm²) at Tchabbal. On the other hand, this value is lowest in *V. paradoxa* (0.00 g/ cm²) and *H. madagascariensis* (0.00 g/ cm²) at Dang, in *T. glaucescens* (0.01 g/ cm²) at Tchabbal and in *F. thonningii* (0.01 g/ cm²) at the Cliff. The other species had intermediate values at each of the three sites.

Leaf specific mass varied significantly ($P < 0.001$) between

sites (Table 20). Overall, the value at Tchabbal (0.01 g/ cm²) was lower than those at the other two sites (0.02 g/ cm²), which did not differ significantly. By species, the sites do not differ significantly in *C. macrostachyus*, *F. thonningii* and *P. febrifugum*. For *H. madagascariensis*, the value increases with altitude, rising from 0.00 g/ cm² at Dang to 0.02 g/ cm² at the Cliff, with an intermediate value at Tchabbal (0.01 g/ cm²). In the case of *F. sur*, *P. thonningii* and *T. glaucescens*, the value of the specific leaf mass at the Cliff is higher than those at Dang and Tchabbal, which do not differ significantly between these two sites. For the rest of the species, there was no clear trend in the variation in leaf density between study sites. The interaction between sites and species was also significant (Table 21), with an F value of 64.73 and $P < 0.001$.

Species	Dang	Tchabbal	Cliff	Average	F
AS	0.02 ± 0.01 β g	0.01 ± 0.00 α cd	0.01 ± 0.00 α c	0.01 ± 0.00 D	13.50***
CM	0.01 ± 0.00 α bc	0.01 ± 0.00 α ab	0.01 ± 0.00 α ab	0.01 ± 0.00 AB	5.78ns
HM	0.00 ± 0.00 α a	0.01 ± 0.00 β cd	0.02 ± 0.00 γ f	0.01 ± 0.00 C	189.37***
FS	0.01 ± 0.00 α b	0.01 ± 0.00 β bc	0.02 ± 0.00 γ e	0.01 ± 0.00 C	48.96***
FT	0.01 ± 0.00 β de	0.01 ± 0.00 α β ad	0.01 ± 0.00 α a	0.01 ± 0.00 B	2.85ns
HA	0.01 ± 0.00 α cd	0.01 ± 0.00 β de	0.01 ± 0.00 β cd	0.01 ± 0.00 C	27.97***
PT	0.01 ± 0.00 α ef	0.01 ± 0.00 α ef	0.02 ± 0.01 β e	0.01 ± 0.01 DE	5.90*
PF	0.02 ± 0.01 α ef	0.01 ± 0.01 α ef	0.01 ± 0.00 α cd	0.01 ± 0.01 DE	1.25ns
SG	0.01 ± 0.00 α cde	0.02 ± 0.00 β g	0.02 ± 0.00 β e	0.02 ± 0.00 E	54.34***
TG	0.01 ± 0.00 α bcd	0.01 ± 0.00 α a	0.02 ± 0.00 β de	0.01 ± 0.00 C	60.54***
VP	0.00 ± 0.00 α a	0.01 ± 0.00 β abc	0.01 ± 0.00 β bc	0.01 ± 0.00 A	81.72***
XA	0.06 ± 0.03 γ h	0.02 ± 0.01 α g	0.03 ± 0.02 β g	0.03 ± 0.02 F	91.87***
Average	0.02 ± 0.01 B	0.01 ± 0.00 A	0.02 ± 0.01 B	0.01 ± 0.00	
F	168.83***	17.17***	30.24***		

Numbers followed by different Arabic letters (a. b. c. d. e. f. g. h) in columns, different Greek letters (α. β and γ) and capital Arabic letters (A. B. C.) in rows (means), are significantly different at *** $P < 0.001$.

AS= *Annona senegalensis*; **CM**= *Croton macrostachyus*; **HM** = *Harungana madagascariensis*; **FS** = *Ficus sur*; **FT** = *Ficus thonningii*; **HA** = *Hymenocardia acida*; **PT** = *Piliostigma thonningii*. **PF** = *Psorospermum febrifugum*; **SG**= *Syzygium guineense* var. *guineense*; **TG** = *Terminalia glaucescens*; **VP**= *Vitellaria paradoxa*; **XA**= *Ximenia Americana*.

Table 20: Interspecific and inter-site variation in leaf density (g/ cm²).

Source	SC	DL	MC	F
Species	0.22	11	0.02	147.27***
Sites	0.01	2	0.00	41.48***
Species × sites	0.20	22	0.009	64.73***

Sum of squared differences (SC). Degree of freedom (DL). Mean of squared differences (MC), significant difference at : *** : $P < 0.001$.

Table 21: Two-factor analyses of variance (species and sites) for specific mass.

Leaf Density Variation

The leaf density of the 12 woody plants varied significantly ($P < 0.001$) between species and sites (Table 22). With an overall mean value of 0.08 g/mm^3 , leaf density was highest in *X. americana* (0.14 g/mm^3), lowest in *F. thonningii* (0.04 g/mm^3) and intermediate in the other species.

In each of the three sites, leaf density varied significantly ($P < 0.001$) between species (Table 22). It was highest in *X. americana* (0.020 g/mm^3) and lowest in *H. madagascariensis* (0.02 g/mm^3) at Dang; highest in *A. senegalensis* (0.12 g/mm^3) and lowest in *H. madagascariensis* (0.02 g/mm^3) at Tchabbal, and the highest for *S. guineense* var. *guineense* (0.18 g/mm^3) and the lowest for *F. thonningii* (0.04 g/mm^3) at the Cliff. The other species had intermediate values at each of the three sites.

Leaf density varied overall and significantly ($P < 0.001$) between sites (Table 22). Overall, the value at Cliff (0.10 g/mm^3) was significantly higher than those at Dang (0.06 g/mm^3) and Tchabbal (0.07 g/mm^3), which did not differ significantly. By species, in *H. acida*, *P. thonningii* and *S. guineense* var. *guineense*, the value of leaf density increased with altitude, from Dang to the Cliff, via Tchabbal. In the case of *H. madagascariensis*, *F. sur* and *P. febrifugum*, the leaf density value at the Cliff is higher than those at Dang and Tchabbal, which do not differ significantly between the letter two sites. For the rest of the species, there was no clear trend in leaf density variation between study sites. The interaction between sites and species was also significant (Table 23), with an F value of 56.89 and $P < 0.001$.

Species	Dang	Tchabbal	Cliff	Average	F
AS	$0.07 \pm 0.03 \alpha \text{ ef}$	$0.12 \pm 0.07 \beta \text{ g}$	$0.13 \pm 0.08 \beta \text{ d}$	$0.11 \pm 0.07 \text{ I}$	32.71***
CM	$0.05 \pm 0.03 \beta \text{ cd}$	$0.04 \pm 0.01 \alpha \text{ b}$	$0.06 \pm 0.03 \gamma \text{ b}$	$0.05 \pm 0.02 \text{ AB}$	20.94***
HM	$0.02 \pm 0.01 \alpha \text{ a}$	$0.02 \pm 0.01 \alpha \text{ a}$	$0.15 \pm 0.08 \beta \text{ e}$	$0.06 \pm 0.05 \text{ DE}$	292.14***
FS	$0.07 \pm 0.05 \alpha \text{ fg}$	$0.07 \pm 0.06 \alpha \text{ cd}$	$0.10 \pm 0.06 \beta \text{ c}$	$0.08 \pm 0.06 \text{ G}$	12.81***
FT	$0.05 \pm 0.05 \beta \text{ d}$	$0.04 \pm 0.02 \alpha \text{ b}$	$0.04 \pm 0.03 \alpha \text{ a}$	$0.04 \pm 0.03 \text{ A}$	9.55**
HA	$0.04 \pm 0.02 \alpha \text{ bc}$	$0.08 \pm 0.04 \beta \text{ e}$	$0.09 \pm 0.04 \gamma \text{ c}$	$0.07 \pm 0.04 \text{ EF}$	90.34***
PT	$0.05 \pm 0.02 \alpha \text{ cd}$	$0.08 \pm 0.06 \beta \text{ de}$	$0.09 \pm 0.03 \gamma \text{ c}$	$0.07 \pm 0.04 \text{ F}$	33.79***
PF	$0.08 \pm 0.06 \alpha \text{ g}$	$0.07 \pm 0.04 \alpha \text{ c}$	$0.14 \pm 0.09 \beta \text{ d}$	$0.09 \pm 0.07 \text{ H}$	34.48***
SG	$0.05 \pm 0.01 \alpha \text{ cd}$	$0.06 \pm 0.03 \beta \text{ c}$	$0.18 \pm 0.07 \gamma \text{ f}$	$0.10 \pm 0.07 \text{ H}$	335.58***
TG	$0.05 \pm 0.03 \beta \text{ de}$	$0.04 \pm 0.02 \alpha \text{ b}$	$0.06 \pm 0.02 \gamma \text{ b}$	$0.05 \pm 0.03 \text{ BC}$	16.60***
VP	$0.03 \pm 0.02 \alpha \text{ b}$	$0.10 \pm 0.04 \gamma \text{ f}$	$0.05 \pm 0.03 \beta \text{ ab}$	$0.06 \pm 0.04 \text{ CD}$	102.79***
XA	$0.20 \pm 0.14 \gamma \text{ h}$	$0.09 \pm 0.04 \alpha \text{ ef}$	$0.12 \pm 0.10 \beta \text{ d}$	$0.14 \pm 0.12 \text{ J}$	36.31***
Average	$0.06 \pm 0.05 \text{ A}$	$0.07 \pm 0.05 \text{ A}$	$0.10 \pm 0.07 \text{ B}$	0.08 ± 0.07	
F	86.76***	51.79***	62.42***		

Numbers followed by different Arabic letters (a. b. c. d. e. f. g. h) in columns, different Greek letters (α , β and γ) and capital Arabic letters (A. B. C.) in rows (means), are significantly different at *** $P < 0.001$.

AS= *Annona senegalensis*; **CM**= *Croton macrostachyus*; **HM** = *Harungana madagascariensis*; **FS** = *Ficus sur*; **FT** = *Ficus thonningii*; **HA** = *Hymenocardia acida*; **PT**=*Piliostigma thonningii*. **PF** = *Psorospermum febrifugum*; **SG**= *Syzygium guineense* var. *guineense*; **TG** = *Terminalia glaucescens*; **VP**= *Vitellaria paradoxa*; **XA**= *Ximenia Americana*.

Table 22: Inter-specific and inter-site variation in leaf density (g/mm^3)

Source	SC	DL	MC	F
Species	3.50	11	0.31	93.07***
Sites	1.43	2	0.71	210.23***
Species \times sites	4.28	22	0.19	56.89***

Sum of squared differences (SC). Degree of freedom (DL). Mean of squared differences (MC), significant difference at : *** : $P < 0.001$

Table 23: Two-factor analyses of variance (species and sites) for leaf density.

Individuals Height variation

The height of woody individuals varied significantly ($P < 0.001$) between the study sites and species (Table 24). With an overall mean value of 4.39 m, the height of woody plants was highest in *S. guineense* var. *guineense* (9.71 m), lowest in *H. acida* (1.87 m) and intermediate in the other species.

In each of the three sites, the height of individuals varied significantly ($P < 0.001$) between species (Table 24). Height was highest in *S. guineense* var. *guineense* at all three sites, with values of 11.50 m, 8.71 m and 8.92 m at Dang, Tchabbal and at the Cliff respectively. This height value is lowest for *H. acida* (1.80 m) at Dang, for *P. febrifugum* (1.76 m) at Tchabbal and for *A. senegalensis* (1.72 m) and *H. acida* (1.77 m) at the Cliff. The other species show intermediate values for each of the three sites.

Overall, the height of the woody plants varied significantly ($P < 0.001$) between sites (Table 24). Overall, the height of woody plants decreased with altitude, from 5.08 m at Dang to 3.80 m at the Cliff, with an intermediate value at Tchabbal (4.29 m). By species, for seven species (*A. senegalensis*, *C. macrostachyus*, *H. madagascariensis*, *F. thonningii*, *P. thonningii*, *T. glaucescens* and *V. paradoxa*), the height of woody plants decreased with altitude, from Dang to the Cliff, via Tchabbal. In the case of *P. febrifugum*, *S. guineense* var. *guineense* and *X. americana*, the height of woody plants at Dang was significantly higher than at Tchabbal and at the Cliff, which did not differ significantly between the letter two sites. The interaction between sites and species was also significant (Table 25), with an F value of 35.86 and $P < 0.001$.

Species	Dang	Tchabbal	Cliff	Average	F
AS	2.40 ± 0.5 γ bc	1.84 ± 0.32 β ab	1.72 ± 0.18 α a	1.98 ± 0.49 AB	119.84***
CM	6.64 ± 1.55 γ f	5.64 ± 1.38 β d	4.78 ± 0.79 α d	5.69 ± 1.49 F	72.80***
HM	2.63 ± 0.51 γ c	2.24 ± 0.55 β c	2.08 ± 0.47 α b	2.32 ± 0.56 C	42.04***
FS	5.57 ± 0.68 β e	5.50 ± 1.28 β d	4.90 ± 1.01 α d	5.32 ± 1.06 E	18.18***
FT	6.90 ± 1.17 γ g	6.07 ± 1.47 β e	4.50 ± 1.49 α c	5.82 ± 1.70 FG	107.81***
HA	1.80 ± 0.16 α a	2.05 ± 0.60 β bc	1.77 ± 0.17 α a	1.87 ± 0.39 A	24.52***
PT	3.24 ± 0.60 γ d	2.32 ± 0.42 β c	2.04 ± 0.22 α b	2.53 ± 0.68 D	276.20***
PF	2.34 ± 0.43 β b	1.76 ± 0.26 α a	1.77 ± 0.33 α a	1.96 ± 0.44 AB	123.92***
SG	11.50 ± 1.79 β i	8.71 ± 1.91 α g	8.92 ± 2.40 α f	9.71 ± 2.41 I	79.58***
TG	8.78 ± 1.41 γ h	7.50 ± 0.94 β f	6.42 ± 1.32 α e	7.57 ± 1.91 H	70.53***
VP	6.85 ± 0.95 γ fg	5.92 ± 0.25 β e	4.78 ± 0.64 α d	5.85 ± 1.20 G	202.74***
XA	2.30 ± 0.52 β b	1.95 ± 0.25 α ab	1.87 ± 0.10 α ab	2.04 ± 0.38 B	59.68***
Average	5.08 ± 3.14 C	4.29 ± 2.67 B	3.80 ± 2.43 A	4.39 ± 2.81	
F	1372.80***	669.50***	732.84***		

Numbers followed by different Arabic letters (a. b. c. d. e. f. g. h) in columns, different Greek letters (α. β and γ) and capital Arabic letters (A. B. C.) in rows (means), are significantly different at *** $P < 0.001$.

AS= *Annona senegalensis*; **CM**= *Croton macrostachyus*; **HM** = *Harungana madagascariensis*; **FS** = *Ficus sur*; **FT** = *Ficus thonningii*; **HA** = *Hymenocardia acida*; **PT** = *Piliostigma thonningii*. **PF** = *Psorospermum febrifugum*; **SG**= *Syzygium guineense* var. *guineense*; **TG** = *Terminalia glaucescens*; **VP**= *Vitellaria paradoxa*; **XA**= *Ximenia Americana*.

Table 24: Interspecific and inter-site variation in foot height (m).

Source	SC	DL	MC	F
Species	32104.60	11	2918.6	2618.86***
Sites	1402.12	2	701.06	629.06***
Species × sites	879.16	22	35.86	35.86***

Sum of squared differences (SC). Degree of freedom (DL). Mean of squared differences (MC), significant difference at : *** : $P < 0.001$.

Table 25: Analyses of variance with two factors (species and sites) concerning the height of ligneous plants.

Discussion

Inter-site variation in these morphological traits allows two groups to be distinguished: those whose values decrease with the altitudinal gradient (length, width, fresh and dry mass, leaf area, Leaf specific area and individual height), and those whose values increase with the altitudinal gradient (water content, thickness, dry matter content, specific mass and leaf density).

In the first group, all the traits vary significantly between sites (environment) and species (biotic), as well as between their interaction. Overall, it is characterised by size-related traits, and it seems clear that leaf size decreases with altitude. In the case of this study, the length, width and fresh and dry masses of the leaves also decrease, with the exception of certain species such as *H. acida*, *T. glaucescens*, *F. sur.*, *P. febrifugum* and *X. americana* for width, which do not respect this rule. These variations may be linked to the physiology of each woody. The leaf development of *P. thonningii*, for example, is more marked in the direction of its width, unlike the other species. In relation to fresh mass, the loss of water through the leaves with altitude does not lead to a change in the order of dry mass values obtained here. On the other hand, it was found that species such as *H. acida* and *X. americana*, although small in size, have large thickness values. This could be explained by the fact that species with small leaf areas generally invest more in thickness, which leads to slow growth and therefore a high capacity for conserving resources. In relation to soil fertility, Garnier [62] believe that this type of species, when abundant in an environment, indicates that the environment is not very fertile.

Leaf area decreases with altitude in this study. This could be explained by the fact that the altitudinal environment becomes more restrictive for these species the higher up you go. It's true that the larger the leaf area, the more photosynthesis takes place and the better the plant functions, but ultimately it varies according to the environment and/or even the altitude. We share the same climate, but temperature and soil could also account for the variations observed. In the same vein, Mapongmetsem [44] show that leaves with reduced surface area limit transpiration while ensuring good photosynthesis of carbohydrates. Some authors believe that the ferralitic nature of the soil in Adamaoua could explain the variations observed in plants in various habitats. Specifically in Cameroon. Martin and Segalen [45] explain that the soil in Adamaoua becomes less ferralitic towards the northern edge of the plateau. i.e. towards the cliffs. In the same vein. Nalovic and Pinta [40], also on Madagascar soils, concluded that ferralitic soils were relatively richer than tropical ferruginous soils. The results obtained here in Cameroon and presented in this study confirm and clarify the value of this

conclusion: at higher altitudes, plants are smaller in size and develop their root systems to a greater extent.

Leaf specific area thus reflects the opposition between investment in growth (high specific surface area) versus investment in defences and reserves (low specific surface area) [46]. According to Wright [46], species with a high specific surface area have sparse leaf tissue, a high rate of photosynthesis and a high growth rate, resulting in a high capacity to acquire resources (exploitative species, dominant in fertile environments). On the other hand, species with a low specific surface area have dense leaf tissue and grow slowly, resulting in a high capacity to conserve resources (conservative species, dominant in less fertile environments).

The height of the trees also decreases as you move towards the Cliff. Where the altitude is around 1.600 metres. Climatic conditions could explain this result. Altitude increases as you go towards the Cliff, and tree leaves tend to reduce in size in order to adapt better to these conditions. These results are in line with those obtained in a study carried out by Korner [47] in a temperate climate. In his study, he showed that the subalpine environment is subject to harsh climatic conditions, since altitude interacts with other factors such as temperature, rainfall, snow cover, length of vegetation, light and wind strength.

For Nyasiri [34], in the Sudano-Guinean savannas, other factors such as bush fires, overgrazing. etc. would provide additional explanations for these variations. Being a livestock area par excellence, there are generally many herds of cattle grazing on the Falaise de Ngaoundere. All these pressures could therefore to some extent explain the decline in leaf size in the Falaise de Ngaoundere. Chalvin [48] showed in a study that the mountain environment is an environment where the responses of individuals to biotic and abiotic conditions are very marked.

Overall, then, at morphological level, it has long been known that climate and soil characteristics influence leaf size, shape and structure [49-54]. The temperature increases towards the north of Cameroon. Review articles generally show an increase in the specific mass and density of mesophyll in response to stresses such as low rainfall, high light levels, extreme temperatures or ozone pollution [55,56].

In the second group, for the majority of species, the traits vary significantly between sites (environment) and species (biotic), as well as between their interaction. This group is made up of traits whose values increase with altitude (water content, thickness, dry matter content, specific mass and leaf density). The increase in thickness of most species with altitude is due to the fact that climatic conditions are harsher

for these species, which develop their root system more. The leaves of these species therefore become denser.

Wright [57] point out in a study that tree leaves tend to be harder, denser and have a smaller specific surface area. In the savannah, species have to constantly regulate the inflow and outflow of water into and out of their bodies, so they have to reduce certain trait values (leaf area and specific surface), to the detriment of other traits (density, water content. etc.). In terms of ecosystem functioning. Westoby [58] shows that the link between dry matter content and specific surface area is even more appreciated when we look at the ecological strategies reflected by these functional traits. Plants with a high specific surface area and low dry matter content will grow rapidly and acquire resources efficiently in the short term in relation to the amount of organic matter invested. Conversely, plants with a high dry matter content and low specific surface area grow less quickly but have longer-lasting leaves, which enable them to store nutrients. A high rate of photosynthesis is associated with thin leaves. i.e. high specific surface area [57] and low dry matter content [60,61].

Garnier [62] showed that dry matter content provides an approximation of leaf tissue density and is correlated with the nutrient conservation strategy within the plant. In a similar vein. Souto [63] showed in a study of a tropical tree (*Embothrium coccineum*) that an increase in specific mass (smaller, thicker leaves) is a response to increased heat and drought in summer. This variation in specific mass is also linked to light management. This certainly explains why, at the same level of light, tolerant species have lower specific masses (high specific surface area and small thickness) than other species [64-66]. In any case, intolerant species are known to have thicker leaves [67,68,64,69]. Species characteristic of undergrowth also have longer-lived leaves associated with lower specific masses [70,71].

The conditions in each environment influence the different traits studied. The altitudinal gradient reveals these different variations. Most of the traits show a clear regression with altitude, while others show an increase.

Conclusion

At the end of this study, the twelve traits associated with the species in our study had practically the same variation trend from one site to another. Some of them vary from 0.12 mm to 0.30 mm respectively in *S. guineense* var. *guineense* and *A. senegalensis* at Dang; and from 0.13 mm to 0.33 mm respectively in *A. senegalensis* and *H. acida* at the Cliff, for thickness; from 12.14 cm² to 119.12 cm² at Dang; and from 9.35 cm² to 107.90 cm² at the Cliff for leaf area. It varies from 22.32 cm²/g to 268.09 cm²/g respectively in *X. americana* and *V. paradoxa* at Dang, from 44.19 cm²/g to 135.99 cm²/g

respectively in *H. madagascariensis* and *F. thonningii* at the Cliff; from 0.30 g. g⁻¹ to 0.85 g. g⁻¹ respectively in *C. macrostachyus* and *P. febrifugum* at Dang, and from 0.43 g. g⁻¹ to 0.87 g. g⁻¹ respectively in *H. madagascariensis* and *T. glaucescens* at the Cliff for dry matter content; from 0.00 g/ cm² to 0.06 g/ cm² respectively in *V. paradoxa* and *X. americana* at Dang, from 0.01 g/ cm² to 0.03 g/ cm² respectively in *F. thonningii* and *X. americana* at the Cliff for specific mass; from 0.02 g.mm⁻³ to 0.20 g.mm⁻³ respectively in *H. madagascariensis* and *X. americana* at Dang, and from 0.04 g.mm⁻³ to 0.18 g.mm⁻³ in *F. thonningii* and *S. guineense* var. *guineense* at the Cliff for leaf density. Overall, traits such as tree length, width, fresh mass, dry mass, leaf area, specific surface area and height decrease. Overall, traits such as the length, width, fresh mass, dry mass, leaf area, leaf specific area and height decrease with altitude, i.e. towards the cliff site. Traits such as water content and dry matter content, on the other hand, increase.

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