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Yakandawala, K, Bandara, A, Yakandawala, D and Abeynayake, R (2023) Beyond aesthetics: Integration of textural groups of tropical ornamental shrubs into urban planting designs. Journal of the National Science Foundation of Sri Lanka, 51 (3). pp. 463-477. ISSN 1391-4588

DOI: https://doi.org/10.4038/jnsfsr.v51i3.11068

Publisher: National Science Foundation of Sri Lanka

Version: Published Version

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J.Natn.Sci.Foundation Sri Lanka 2023 51 (3): 463 - 477
DOI: http://dx.doi.org/10.4038/jnsfsr.v51i3.11068

RESEARCH ARTICLE

Environmental Horticulture

Beyond aesthetics: Integration of textural groups of tropical ornamental shrubs into urban planting designs

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Submitted: 26 September 2022; Revised: 05 January 2023; Accepted: 27 January 2023

Abstract: Shrubs are popularly incorporated to establish green infrastructure in urban spaces. We argue that the functions provided by shrubs could be further enhanced by giving due consideration to their leaf morphological characters. Therefore, our objective was to recognise how the different morphological characters of leaves, listed as contributing to determining the plant texture in literature, would collectively contribute to recognizing textural groups of plants, and further, to define each of these groups into either coarse, medium, or fine textural categories using ornamental shrubs. We investigated the quantitative and qualitative leaf morphology of 30 tropical ornamental shrubs in the Peradeniya area. According to our analysis, leaf area, petiole length, and internodal distance have significantly contributed to the separation of shrubs into three textural groups; fine, medium and coarse, and were considered as preliminary characters that determine the texture. Leaf hair related characters *viz*., hair densities on upper and lower surfaces, and the length of hairs on both surfaces, together with qualitative morphological characters, *viz*., leaf margins, leaf arrangement, and prominent venation were identified as secondary characters that contributed to defining textural groups. Shrubs with coarse texture possess significantly larger leaves, longer petioles and internodal distances compared to fine textured group. Our recommendation is to consider plant textural groups as a criterion in the selection of plants for planting designs during the establishment of green infrastructure in urban spaces, enabling the obtaining of benefits beyond aesthetics, which include other functional, health and environmental benefits, to improve the quality of life of city dwellers under the context of limited urban green spaces.

Keywords: Green infrastructure, leaf morphology, leaf texture, morphometric analysis, ornamental shrubs, urban space.

INTRODUCTION

Urban spaces occupy a small area (~0.5%) of the Earth's total land surface (Schneider *et al*., 2009). Ironically, 55% of the current world population occupies this space (UN, 2019). This indicates a disproportionate relationship between urbanization and urban land cover. Urbanization is considered a major drive of land cover change worldwide (Grimm *et al*., 2008) and is characterized by expanding built-up areas and population growth in cities (Ren, 2015). As a result, it has led to many environmental issues associated with the reduction of green spaces that could directly have an impact on city dwellers (Seto *et al*., 2012). Consequently, the importance of the wise use of the available urban spaces is a topic of concern.

Moreover, urban vegetation plays a vital role as a major component of green infrastructure (GI) in light of urbanisation. Naumann *et al.* (2011) defined GI as a human-made (or human influenced) infrastructure designed and installed to ease environmental pressure. The multifunctional nature of GI is well-documented and these functions are broadly categorized as economic, ecological and sociocultural (Hansen & Pauleit, 2014). Further, aesthetic value considered under the socio-cultural benefits is a widely perceived component, appreciated and highly valued by city dwellers (Nia & Olugbenga, 2020).

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Urban GI covers a range of landscape types of varying complexity and morphology such as parks, urban forests, roof and vertical greening, and residential gardens (Cameron *et al*., 2012). Ornamental plants, a major component of urban vegetation, play an important role in green infrastructure (GI) in urban landscapes (Natuhara, 2018). They could be categorized under ground covers, herbs, shrubs, trees, and climbers, growing under terrestrial or aquatic habitats. Among them, shrubs are defined as woody plants which produce multiple branches derived from nodes near the base of the plant (Cameroon, 2016). They are popular in anthropogenic landscapes, specifically due to their tolerance to pruning, fast growth rate, variation in form, the striking nature of their leaves with a range of sizes, shapes, and colours contributing to their overall appearance, and attractive flowers and fruits (Jacobson, 1990; The Royal Horticultural Society, 2013; Cameroon, 2016). Further, during management practices, the tolerance to pruning and clipping and ease of propagation by stem cuttings also contribute to their popularity (Dirr, 2009). As a result, shrubs are widely used globally in urban spaces for decorative and other functions by including them in establishing GI such as hedges, borders, beds, and specimen plants (Kendal *et al*., 2008). Adding to that, the height of ornamental shrubs is comparable to the human dimension, compared to trees and could, therefore, be appreciated at the human-eye level (Jacobsen, 1990). Therefore, the rationale for selecting shrubs in this study was to add aesthetic and functional value to their present use. The aesthetic attributes of shrubs which include leaf and flower, their colour and size, shape and texture, and form have been widely used in landscape designs from ancient times (Laurie, 1975). The designs in Roman and Persian times, as well as Mediaeval and Renaissance cultures, to the Victorian era and up to the present time, have led to global appreciation of the colour of flowers (Tobey, 1973; Farahani *et al*., 2016). Particularly from Roman gardens onwards, skilful management practices of shrubs leading to formal hedges and topiaries had further added aesthetics to the design (Laurie, 1975).

With respect to the Sri Lankan context, garden flora was initially elaborated by Macmillan in 1935 in his famous book 'Tropical Gardening and Planting' (Macmillan, 2012). It explained the popular gardening plants (exotics), their management techniques and their applications. Later, the functions of urban plants were discussed in the Guide to Urban Planting in Sri Lanka (Ekanayake, 1982). Though some studies were conducted on popularizing native plants in landscaping (Yakandawala *et al*., 2013; De Mel and Yakandawala, 2016), these plants are not readily available in the market as opposed to exotic plants despite their functional value (Ranasinghe *et al*., 2019).

The benefits of plants are closely related to their external appearance (phenotype) or morphology. Plant morphology has undergone fundamental, conceptual, theoretical, and philosophical changes in recent decades (Sattler & Rutishauser 1997). These changes have redirected the course of research in plant morphology and other fields where they are relevant. Apart from these, plant morphology plays a fundamental role in planting design. Hence, Dobrilovič (2006) highlighted the importance of consideration of morphological characteristics of plants as a criterion for selecting plants in planting designs. The visual properties or morphology of plants is a critical parameter for consumers looking to purchase ornamental plants for immediate aesthetic effect (Schreiner *et al*., 2013; Ferrante *et al*., 2015). Besides, designers are also concerned about the visual properties of plants. Plant texture is an important visual element in creating plant associations (Joardar, 1998). In his famous book on 'Planting Design', Florence Bell Robinson (1940) describes plant texture as the surface quality of all parts of plants. According to Beaulieu (2019), texture most often reflects observations about how a plant part looks in relation to neighbouring plants. Texture is not something people consciously think about; however, we recognize it subconsciously in plant associations (Anderson, 2014). The texture can be viewed from various distances in landscapes, ultimately affecting the viewer's perception (Robinson, 1940). Robinson (2016), further elaborating on the distance relating to plant texture, states that when a plant is observed from a closer distance, *i.e.*, less than about 2 m (where the details are easy to perceive), the leaves' surface nature contributes to the texture, while from moderate distance (about 2–20 m), petiole length, size and shape of leaves and twigs contribute to the plant's visual texture. However, from a far distance, the visual effect of individual twigs and leaves will be lost and the features of the canopy will contribute. At this distance, in addition, the size arrangement of foliage clusters or branches contributes to the determination of texture, due to the 3-D arrangement of the leaves and twigs. When the distance is further increased, the spacing between plants will contribute to the texture of plant associations. In the present study, we concentrate on the plant texture from a close to moderate distance where leaves play an important role. Leaves show tremendous morphological diversity, and these variations affect the overall texture of the plant. At macroscopic and microscopic levels, plant morphology can contribute to the textural groups (Wijesinghe & Yakandawala, 2013). Texts that describe and illustrate planting design categorize texture as fine, medium and coarse (Joardar, 1998; Scarfone, 2007). The effect of different textural groups on visual perception and functions in planting designs is well recognized (Joardar, 1998; Robinson, 2016; Mendez, 2019).

Understanding the texture and placement of plants according to the textural groups is crucial to maintain the balance of the garden. Further, mixing plants of different textures is also important to highlight the opposing textural groups (Beaulieu, 2019). Plant texture is an area that has been poorly researched considering its applications in planting designs. Nevertheless, there have been a few research projects carried out on the role of plant texture in pollution control (Wijesinghe & Yakandawala, 2009; 2013). Accordingly, apart from aesthetics, plants with a coarse texture could reduce particulate air pollutants in urban areas (Pallawala *et al*., 2013).

The popular textbooks (Hackett, 1979; Scarfone, 2007) and extension documents (Hansen, 2019; Lannotti, 2019) in landscape design describe plant texture and its applications in planting designs in detail. Further, they elaborate on this visual property with examples from temperate countries where plants are categorized into textural groups based on how a plant part, particularly leaves, looks relative to similar parts of another plant. According to Joardar (1998), plants are often selected based on expert empirical knowledge in a setting rather than predetermined explicit criteria. In view of filling the above gap, a broader scientific scope backed by a statistical analysis could categorise plants into textural groups with scientific proof. Therefore, in the present research, we addressed the question: Can combinations of leaf morphological characters of shrubs be used to validate textural categories scientifically? Consequently, it is anticipated that the application of the available knowledge in the establishment of GI in urban spaces could enhance city dwellers' quality of life. In this backdrop, this study aimed at recognising how the combination of different vegetative morphological characters that determine the plant texture would contribute to recognising textural categories of popularly used tropical shrubs. We hypothesised that the diversity in morphological characters of leaves and twigs results in different textural categories in shrubs. We have investigated the external leaf morphology of 30 tropical ornamental shrubs used in urban landscaping in Sri Lanka to recognise different textural groups. Our results, which deviated from our expectations, can be applied in the selection of shrubs with different textural groups to obtain not only aesthetics but also other functional and social (manipulating space, focalisation), environmental (reduction of particulate matter pollution, noise amelioration, human thermal comfort), and health benefits (reducing respiratory diseases and stress).

MATERIALS AND METHODS

Location of material collection

Twigs from 24 commonly used ornamental shrub species were collected from the Royal Botanical Gardens, Peradeniya, Sri Lanka, and twigs from four native and two endemic shrub species were collected from a nearby residential garden (2 km apart) for the experiments during the period May to August 2017 (Table 1). The study area receives >1400 mm of average annual rainfall, and average temperatures range from approximately 23.5 ºC to 26.5 ºC.

Collection of material

Seven individual plants were randomly selected to represent each shrub species, and three mature twigs approximately 15 cm in length at 1.5 – 2.5 m height were selected from each individual for recording characters. All collected twigs were treated separately with a different acronym (Table 1). Thereby, altogether 21 branches were collected from each species, tagged and stored in separate polybags and transported immediately to the Horticulture laboratory of the Wayamba University of Sri Lanka.

Table 1: Shrubs used in the study for collecting leaf morphological characters with their respective family and acronym

Botanical name	Family	Acronym	*Conservation status
Allamanda cathartica	Apocynaceae	AC	Exotic
Acalypha hispida	Euphorbiaceae	AH	Exotic
Acalypha inferno	Euphorbiaceae	AI	Exotic
Acalypha siamensis	Euphorbiaceae	AS	Exotic
Acalypha wilkesiana 'Tricolor'	Euphorbiaceae	AW	Exotic
Barleria lupulina	Acanthaceae	BL	Exotic
Barleria prionitis	Acanthaceae	BPR	Locally common
Brunfelsia pauciflora	Solanaceae	BP	Exotic
Cestrum nocturnum	Solanaceae	CN	Exotic
Excoecaria bicolor	Euphorbiaceae	EB	Exotic
Graptophyllum pictum	Acanthaceae	GP	Exotic
Hamelia patens	Rubiaceae	HP	Exotic
Helicteres isora	Malvaceae	HI	Locally common
Hibiscus rosa-sinensis	Malvaceae	HR	Exotic
Ixora coccinea	Rubiaceae	IC	Locally common
Megaskepasma erythrochlamys	Acanthaceae	ME	Exotic
Memecylon umbellatum	Melastomataceae	MU	Locally common
Murraya paniculata	Rutaceae	MP	Locally common
Odontonema strictum	Acanthaceae	OS	Exotic
Osbeckia octandra	Melastomataceae	OO	Locally common
Pseuderanthemum atropurpureum	Acanthaceae	PAT	Exotic
Plumbago auriculata	Plumbaginaceae	PAU	Exotic
Polyscias balfouriana 'Marginata'	Araliaceae	PB	Exotic
Pseuderanthemum graciflorum	Acanthaceae	PG	Exotic
Pentas lanceolata	Rubiaceae	PL	Exotic
Phyllanthus myrtifolius	Phyllanthaceae	PM	Vulnerable
Pseuderanthemum reticulatum	Acanthaceae	PR	Exotic
Syzygium campanulatum	Myrtaceae	SC	Exotic
Sanchezia nobilis	Acanthaceae	SN	Exotic
Thunbergia erecta	Acanthaceae	TE	Exotic

* Source: The National Red List (2020)

Measurement of quantitative morphological characters

Seven quantitative morphological characters were measured in each twig. Internodal length (the lowermost two nodes and averaged in cm) and petiolar length (the lowermost two leaves and averaged in cm) were measured using a meter ruler. The density of leaf hairs (number of hairs under the magnification ×40, dissecting microscope Model-Labomed, USA) and hair length (average of three hairs using light microscope Model-Labomed fitted with eyepiece graticule Model-Reichert) if present in the upper and lower surface of the leaf were measured. Leaf area was measured using a portable leaf area meter (CID Bio Science Model-CI 202).

Measurement of qualitative morphological characters

Five qualitative morphological characters were also measured in each twig. The leaf margin (entire or non-entire), leaf arrangement (opposite, opposite decussate and whorled, or other), nature of leaf surface (smooth or rough), prominent venation (presence or absence), and hairs in petiole (presence or absence) were recorded by visual observations. The characters related to the hairs on leaves and petioles were studied under the dissecting microscope (Model-Labomed).

Statistical analysis

Data from 630 twigs of 210 individuals belonging to 30 species were collected during the study. These morphological characters included both quantitative and qualitative data. All the qualitative data were coded as binary variables. The Kaiser-Meyer-Olkin (KMO) test (Kaiser, 1970) was applied to check the sampling adequacy for the multivariate analysis, while the Pearson correlation coefficient was employed to ensure that the multivariate analysis was not distorted (Rohlf, 2009). Then the quantitative morphological characters and qualitative binary variables were subjected to principal component analysis (PCA). The quantitative variables were represented by their mean values and standardized by subtracting the mean and dividing by the standard deviation to equalize the weights in the construction of the PCA axes. This analysis makes it possible to identify the most suitable variables to group the species (Iezzoni & Pritts, 1991). Then the scree plot based PCA was used to determine the number of PCs retained in the PCA (Eigen value greater than 1) (Kaiser, 1960). Then the Biplot-based representation of the PCA was performed for grouping the species considering the associated characteristics. Cluster analysis of all individuals was done to test the integrity of the PCA grouping. Hierarchical cluster analysis was used to group the species with similar morphological characters. Dendrograms using Ward's linkage method based on Gower distance coefficients (Gower, 1971), were produced to assess the similarity between the species. The correlation coefficient (r) was estimated to measure the distortion between the original matrix and the dendrogram (Sneath & Sokal, 1973; Sebola & Balkwill, 2009). To identify the significant difference among clusters identified by the PCA and cluster analysis, based on quantitative variables, one-way analysis of variance (ANOVA) was carried out with Tukey's HSD mean separation procedure at 95% confidence level. All analyses were performed in Minitab 19 (State College, PA: Minitab, Inc., USA).

RESULTS AND DISCUSSION

Morphometric analysis for textural groups

Principal component analysis based grouping.

Principal component analysis is a powerful approach that allows a better understanding of the structure of the entire group of shrubs (Zimisuhara *et al*., 2015). The KMO test gave a value of 0.68, indicating an adequate sampling for PCA. All 12 variables were retained for the PCA and cluster analysis. The Cophenetic correlation yielded a value of 82 in the PCA, indicating a high Gower distance between species in bi-dimensional and multidimensional space. The first four PCs whose Eigenvalues were greater than one of the PCA accounted for 73.8% of the cumulative variance, and the individual contribution of the PCs is 26.6%, 18.7%, 16.6% and 10%, respectively (Table 2). As the plants employed in the study are from the outdoor environment, it is difficult to expect to capture a higher variation from PCs, where both PC1 and PC2 components explain 47% of the variation. A score plot drawn using PC1 and PC2 factor scores showed a clear grouping pattern among shrub species in the factor plane (Figure 1). The score plot for the first two PCs shows the separation of the three clusters for the 30 species with minimal overlap.

Cluster analysis based grouping

The dendrogram resulting from the cluster analysis identified three distinct clusters for the 30 shrub species, corroborating the PCA clustering (Figure 2). The first cluster showed an early separation at an approximate distance of 5,823.60, including 16 shrub species. The second and third clusters separated at an approximate distance of 1,941.20, encompassing 10 and four shrub species, respectively.

Table 2: Eigen values and variance explained by the four significant principal components

Values	PC 1	PC 2	PC 3	PC 4
Eigen value	3.4267	1.9925	2.2423	1.1986
Proportion of variance	0.286	0.187	0.166	0.100
Cumulative proportion (%)	0.286	0.472	0.638	0.738

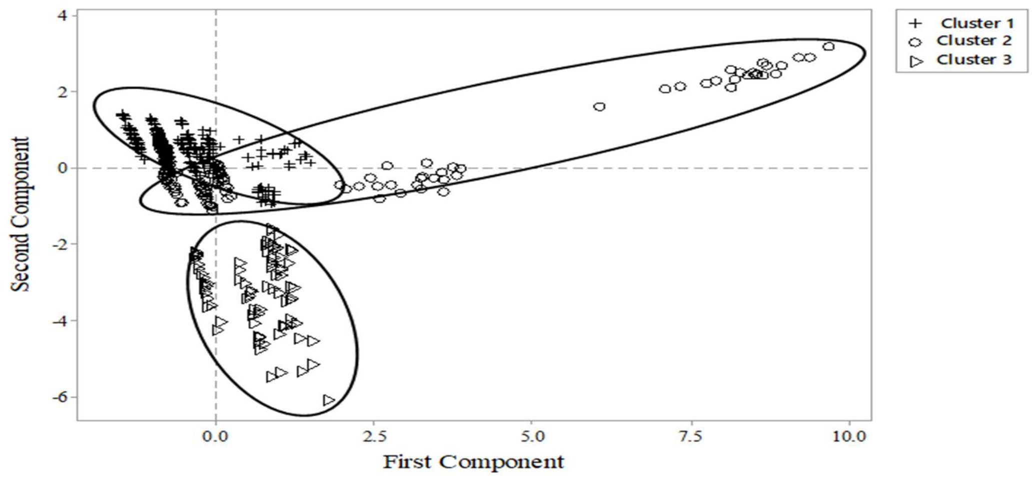

Figure 1: Score plot of first two PCs of the PCA, showing contribution of the quantitative morphological characters. Different symbols represent members of the three clusters (+ = cluster I; o = cluster II; and Δ = cluster III).

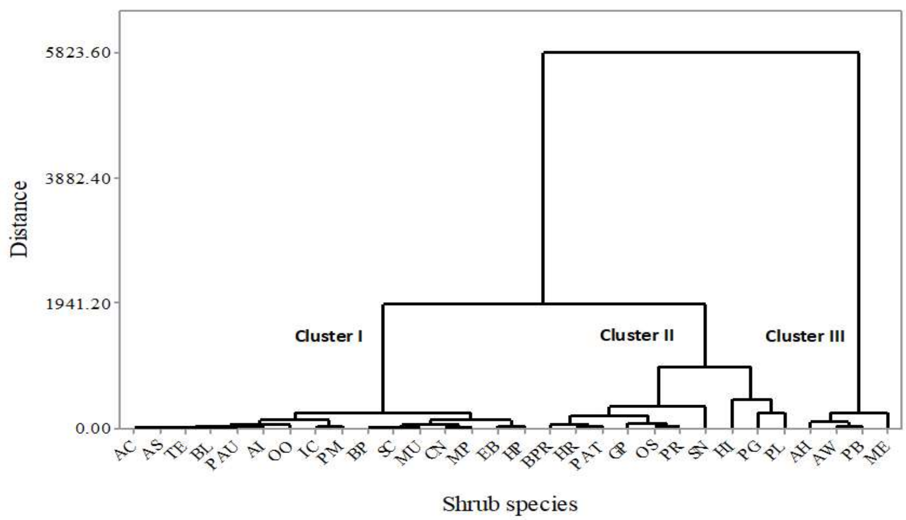

Figure 2: Dendrogram showing the relationship of shrub species based on cluster analysis where species separated into three main clusters.

Contribution of morphological characters for grouping

According to the PCA loadings (Table 3), the characters that contributed to the division of species along the PC1 were leaf lower surface hair density, hair length of upper surface, and lower surface hair length. Along the PC2, internodal distance, total leaf area and prominent venation contributed to the separation. The loading plot for the first two PCs further explained each variable's contribution (Figure 3).

Table 3: PCA loading for the first four highest accounted principal components

Variable	PC1	PC2	PC3	PC4
Internodal distance	0.033	-0.411	-0.287	0.201
Petiole length	0.095	-0.372	0.455	-0.175
Leaf upper (adaxial) surface hair density	0.342	-0.046	-0.275	-0.130
Leaf lower (abaxial) surface hair density	0.506	0.088	-0.123	0.140
Hair length of upper surface	0.478	0.157	0.036	0.217
Hair length of lower surface	0.484	0.144	0.033	0.206
Total leaf area	0.057	-0.527	0.294	0.057
Leaf margin	0.202	-0.067	0.505	0.125
Leaf arrangement	-0.003	0.346	0.460	-0.055
Leaf surface	0.177	-0.038	-0.194	-0.630
Prominent venation	-0.079	0.465	0.150	-0.232
Presence of hair on petiole	0.269	-0.134	0.066	-0.575

The one-way analysis of variance with Tukey mean comparison was carried out to determine the behaviour of quantitative variables on clusters obtained from PCA and cluster analysis. It indicates significant differences in mean values for each variable among the three clusters (Table 4).

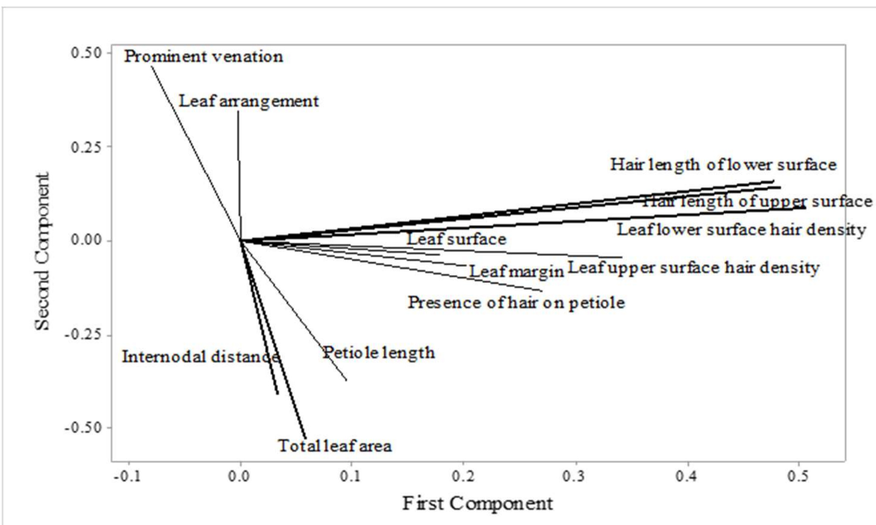

Figure 3: Loading plot (Biplot) of the first two PCs

The analysis indicates that internodal distance, petiole length, and total leaf area are significantly different among the three clusters, while leaf upper surface hair density, leaf lower surface hair density, hair length of upper surface, and hair length of lower surface contributed to the separation of cluster II from clusters I and III. The interval plot for the variables; total leaf area, petiole length, and internodal distance, which contribute significantly to discriminate the three clusters identified by the PCA and cluster analysis, are given in Figures 4a, b and c.

Table 4: Comparison of each variable among clusters using Tukey Mean separation

Morphological character	Cluster 1	Cluster 2	Cluster 3
Total leaf area	85.62[c]	307.9[b]	1133.5[a]
Petiole length	0.59[c]	0.9328[b]	5.217[a]
Internodal distance	2.47[c]	3.889[a]	3.393[b]
Leaf upper surface hair density	8.13[b]	32.9[a]	4.881[b]
Leaf lower surface hair density	5.66[b]	90.2[a]	13.71[b]
Hair length of upper surface	0.049[b]	1.145[a]	0.3800[b]
Hair length of lower surface	0.26[b]	0.746[a]	0.05652[b]

* Means that do not share a letter are significantly different

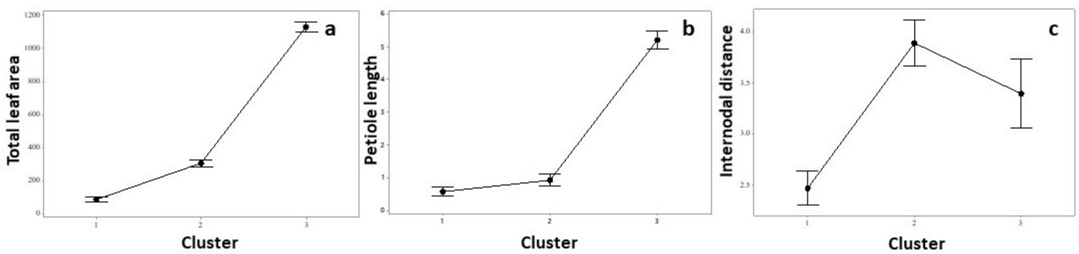

Figure 4: The mean values of a) total leaf area, b) petiole length and c) internodal distance as a function of three different clusters. Error bars depict 95% confidence intervals associated with each of the group means.

Interval plots for the variables leaf upper surface hair density, leaf lower surface hair density, hair length of upper surface, and hair length of lower surface, which significantly discriminate cluster I and cluster III from cluster II identified by the PCA and cluster analysis, are presented in the Figures 5a to 5d.

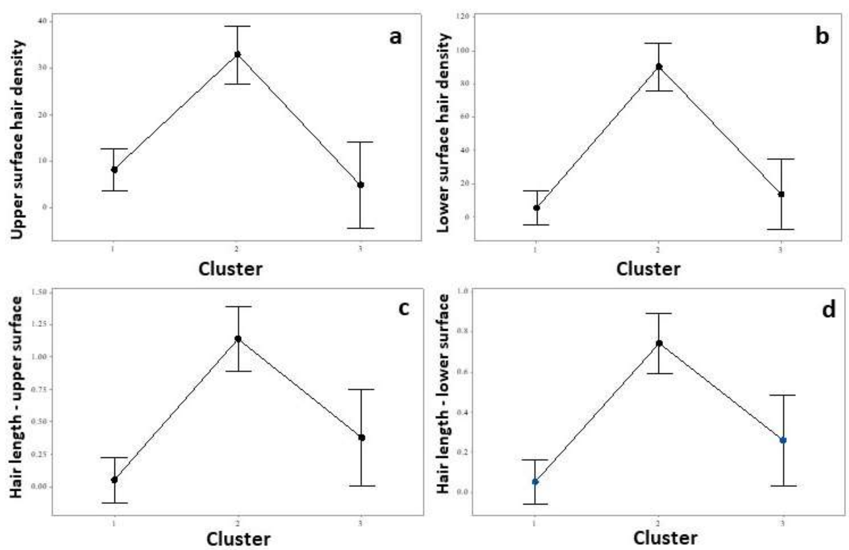

Figure 5: The mean values of leaf hair characters a) upper surface hair density, b) lower surface hair density, c) hair length of the upper surface, and d) hair length of the lower surface as a function of three different clusters. Error bars depict 95% confidence intervals associated with each of the group means.

Landscape professionals tend to utilize plants in designing based on their experience and recommendations. However, the selection of plants based on scientific evidence would result in an improved outcome. In the present study, we have performed a morphometric analysis to categorize shrubs into different textural groups and define the characters that contribute to these groupings. Subsequently, we argue that plant species should be selected by also considering the texture in addition to their ecological and aesthetical features, which in turn are suitable to perform specific functions in urban spaces. The present study groups 30 tropical ornamental shrubs into three textural groups (Table 5).

Authors describing plant texture recognize the three textural groups as coarse, medium and fine (Blake, 1999; Scarfone, 2007). Accordingly, large leaves, leaflets or needles, broad leaf blades, deeply sinus margins, longer petioles, sparse branching (long internodes), pubescence surfaces, and rough surfaces, which cast deeper shadows contributed to coarse textures. In contrast, fine textured plants have small leaves, leaflets or needles, narrow leaf blades, entire margins, short petioles, dense branching, glossy surfaces and overall smooth surfaces that cast little or no shadows. The medium textured plants are considered as possessing the intermediate characters of both these groups (Steed, 1990; Blake, 1999; Robinson, 2016; Hansen, 2019).

Table 5: Shrubs belonging to fine, medium and coarse textural groups

Textural group	Shrub species
Fine texture	*Acalypha inferno, Acalypha siamensis, Allamanda cathartica, Barleria lupulina Brunfelsia pauciflora, Cestrum nocturnum, Excoecaria bicolor, Hamelia patens Ixora coccinea, Memecylon umbellatum, Murraya paniculate, Osbeckia octandra Phyllanthus myrtifolius, Plumbago auriculata, Syzygium campanulatum, Thunbergia erecta*
Medium texture	*Barleria prionitis, Graptophyllum pictum, Helicteres isora, Hibiscus rosa-sinensis, Odontonema strictum, Pseuderanthemum atropurpureum, Pseuderanthemum reticulatum, Pentas lanceolata, Sanchezia nobilis, Pseuderanthemum graciflorum*
Coarse texture	*Acalypha hispida, Acalypha wilkesiana* 'Tricolor' *Megaskepasma erythrochlamys, Polyscias balfouriana*'Marginata'

Corroborating their grouping, the leaf area, petiole length and internodal distance significantly contributed to the separation of the three different textural groups (Table 4). Accordingly, cluster I, encompassing the majority of shrubs, could be categorized as fine textured, and cluster III could be categorized as coarse textured while cluster II was categorized as medium textured (Figure 2). Our results indicate that the shrubs with coarse texture possess significantly large leaves, longer petioles, and longer internodal distances than fine textured groups. These morphological characters give a somewhat lax / loose appearance to the shrubs. On the other hand, the fine textured group gives a dense visual appearance. The medium textured group possessed an intermediate of the above characters compared to the two other groups. However, this group has significantly high internodal distances and this deviation is due to the exceptionally long mean internodal distances (8.514 ± 0.271) recorded in a single shrub *Sanchezia nobilis* (results not given). However, the character 'pubescence surfaces' used to describe plants with coarse texture and 'smooth surfaces' in defining fine texture (Scarfone, 2007; Robinson, 2016), did not contribute to this separation, where the medium texture group (cluster II) exhibited significantly higher hair densities on upper and lower surfaces, together with longer hairs. The term 'pubescence' defining leaf surface nature is a general term for separating a glabrous or shiny surface from a rough surface that possesses hairs or trichomes. According to our findings, the presence of hairs is not a strong character to define textural groups as the shrubs that were included in all three groups possessed hairs to some extent, while the medium textured group exhibited a significantly high amount of hair related characters, contributing to higher leaf hair densities on lower and upper surfaces, together with longer hairs. Of the sixteen shrub species that are included in the fine texture group, three species, *viz*., *A. inferno*, *O. octandra,* and *H. patens,* exhibited hair related characters (results are not given). Similarly, the leaf margin, a qualitative character used to define textural groups (Robinson, 2016), has not contributed to defining textural groups during the analyses. With regard to leaves with non-entire margins, such as serrate and dentate leaves, even though they contribute to increasing the surface areas of a leaf (leaf size), this character cannot be considered a decisive feature in defining textural groups.

Based on our results, we propose that leaf area, petiole length, and internodal distance are the non-overlapping morphological characters that contribute to the separation of the textural groups. Hence, these can be considered as primary characters. In contrast, hair related characters together with qualitative morphological characters such as leaf margins, leaf arrangement, and prominent venation contribute as secondary characters in defining textural groups. The latter two characters are additional features identified as contributing to defining textural groups during the present study. Plants with opposite, opposite-decussate, or whorled leaf arrangements contribute to a dense canopy, and hence these would contribute to a fine texture, while alternate and spiral arrangements would contribute towards an open canopy resulting in a coarse texture. Further, leaves with prominent venation also contribute to a coarse texture as this gives a rough nature and increases the surface area. In addition to the characters accepted as contributing to textural groups, the optical characteristics of the leaf surface, such as leaf cuticle and architecture of the leaf epidermal cells, could also play a role as these contribute to light reflectance. Thin cuticles reflect limited light while thick cuticles reflect more light (Mulroy, 1979; Pfündel *et al*., 2006). The shape of epidermal cells contributes to light reflectance, whereas curvature of the outer epiclinal cell wall reduces reflectance (Karabourniotis *et al*., 2021). According to Xie (2013), when the light bounces back into the viewer's eyes, it enables the viewer to perceive the image as being somewhere it does not actually exist. Hence, the light reflectance could produce eye-catching, striking effects on the plant where the respective plant texture could be highlighted.

The defined textural groups identified have many practical applications in establishing GI in urban spaces, where correct identification of textural groups of shrubs followed by the implementation at the appropriate location would provide not only aesthetic benefits but also many other benefits. The fine textured shrubs have a tight and controlled overall form (Scarfone, 2007; Robinson, 2016) due to its smaller leaves, shorter internodal distances and shorter petioles. Hence, these shrubs are used to establish formal hedges in urban spaces where a sense of order is preferred. Fine textured shrubs such as *A. siamensis, A. inferno, I. coccinea, P. myrtifolius, E. bicolor, H. patens, B. lupulina,* and *S. campanulatum* are popularly used in tropical anthropogenic landscapes to establish formal hedges. According to Robinson (2016), fine-textured species, when tightly clipped, are expressed with the greatest precision. Hence, shrubs such as *A. siamensis, A. inferno, I. coccinea,* and *P. myrtifolius* are popularly used to create topiary in geometrical/formal planting designs in the tropics. Specifically, shrubs used to establish formal hedges and topiary should possess small leaves (dense canopy) as regular clipping is practiced during maintenance. If large leaved shrubs (coarse-textured) are used during clipping, the remaining leftover parts of the leaves in the formal hedges and topiary will give an overall unsightly appearance. Further, it would be difficult to maintain a desirable shape with shrubs with larger leaves and a loose canopy. In establishing informal hedges, where flower and fruit formation is not restricted by regular clipping, any textural group could be incorporated. According to Brun and Dinius (2015), the management practice adopted in maintaining informal hedges is selective pruning, using thinning to maintain the desired height and width. In the tropics, coarse textured shrubs which possess larger leaves such as *P. balfouriana* and *A. wilkesiana 'Tricolor'* and medium textured shrubs which possess medium size leaves such as *G. pictum* and *P. reticulatum* are popularly used in the establishment of informal hedges.

Another application of shrubs in an urban context is their ability to manipulate the apparent size of a space. Scarfone (2007) and Hansen (2010) described that incorporating fine textured shrubs in planting designs tends to make a small space seem larger. With a high proportion of fine-textured plants, it is possible to increase the sense of spaciousness within an enclosure. This effect will add satisfaction and value to the urban dwellers where space could be a limiting factor. In contrast, the incorporation of coarse textured shrubs has the reverse effect. The details of planting design affect the psychological well-being of individuals and the subsequent effect on their social behaviour (Jacobsen, 1990). In extreme applications, when used inappropriately, coarse textured plants can create negative outdoors. According to Robinson (2016), when shrubs with coarse textured foliage are used in confined urban spaces, the advancing effect of the coarse foliage creates a space that feels smaller, causing a claustrophobic effect (fear of confined spaces) for the users. Fine textured plants are easy to look at, and they do not demand the viewers' attention (Scarfone, 2007). Hence, plant associations with fine textured shrubs could be promoted in areas designated for relaxation in public parks and residential gardens, contributing to stress reduction and resulting ultimately in human well-being. In particular, according to Jacobsen (1990), people with visual impairments appreciate coarse vs smooth textured leaves. The coarse texture is dominant over fine texture, and therefore the eyes of the viewers are attracted and held by the coarse textured plants for a longer period (Hansen, 2019). Hence, coarse textured plants such as *M. erythrochlamys* could be incorporated as specimen plants in planting designs to focus the eye, which would help divert attention from less interesting features.

To break the monotony of plant associations, different textural groups can be combined. This can be practised when designing plant borders. According to Hansen (2019), to bridge the gap between the coarse and fine textured foliage, medium textured shrubs could be incorporated. To increase the sense of depth in planting composition, coarse textured shrubs could be placed in the foreground and fine textured shrubs could be placed in the background of a design (Hansen & Alvarez, 2019). Lannotti (2019) suggests that when combining different textural groups in plant associations, as a thumb of rule, a perfect balance can usually be achieved by blending about 1/3 fine texture with 2/3 coarse texture.

Apart from the aesthetics, different textural groups in planting designs could be used to achieve health and environmental benefits by combating air pollution. The interception ability of dust/particulate matter present in the air is positively correlated with the internodal distance, petiole length, leaf area, leaf orientation, margin, folding, arrangement, prominent venation, presence of hairs in leaves; in particular leaf hair density, hair type and length (Varshney & Mitra, 1993; Yunus *et al*., 1995; Hegazy, 1996; Chaphekar, 2000; Wijesinghe & Yakandawala 2009; Das & Prasad, 2012). Specifically, characters, which contribute to increasing the surface area, can contribute in a positive manner (Leonard *et al*., 2016). Shrubs with coarse and medium textured plants possess a majority of these favourable morphological characters, positively contributing to the interception of dust /particulate matter present in the air.

Noise has pervasive auditory (psychological) and non-auditory (hypertension, cardiovascular diseases etc.) effects on human beings (Basner *et al*., 2014; Lim *et al*., 2018). Green infrastructure can provide varying levels of noise mitigation, and the introduction of buffers with evergreen trees and shrubs has been recommended (Bentrup, 2008). The effectiveness of a noise barrier in a given area has been related to the structure, size, and density of the vegetation (Fang & Ling, 2005; Van Renterghem *et al*., 2012). According to Capotorti *et al*. (2016), large leaves are more effective in noise attenuation. Thus, shrubs with a coarse texture can contribute to noise attenuation more than smooth textured shrubs. According to studies conducted by Leuzinger *et al*. (2010) and Nicotra *et al*. (2011), species with large leaf lamina often have a high stomatal density and more open stomatal pores, which allow greater latent heat loss when water is available and consequently contribute to the reduction of urban heat island effect. Hence, as coarse textured shrubs possess larger leaves, they are capable of increasing human thermal comfort.

Compared to temperate countries, in the tropics, the texture of shrubs does not change with the seasons as the majority are evergreen. However, plant physiognomy could change depending on the geography, which could influence the texture. Nevertheless, garden plants are subjected to agronomic practices (irrigation, manuring). Therefore, these plants receive favourable conditions irrespective of geography. Hence we could expect a minimum impact on texture. On the other hand, when plants are introduced from their natural environment to man-made urban structures such as roof gardens and planters, plants are subjected to extreme microclimates such as heat stress, drought and soil conditions (Dvorak & Bousselot, 2021). Consequently, plants develop different morphological, anatomical, and physiological adaptations of the leaves, stems and roots in order to survive in these environments. Particularly high temperatures and droughts can diminish the leaf expansion rate and reduce leaf sizes (Petra *et al*., 2020). These could indirectly influence the texture. Future studies are recommended on the investigation of the effects of physiognomy and man-made urban structures on the visual quality of shrubs.

Understanding the morphological features of shrubs and categorizing them into textural groups could optimize the species selection process of landscape practitioners. The correct plant selection for the right place could guarantee the delivery of shrubs' multiple functions when incorporating them into GI. Finally, city dwellers, the end-users, could enjoy the aesthetic benefits of shrubs while reaping the other benefits.

CONCLUSION

Most shrubs incorporated into urban GI could fulfil the intended functions. However, we argue that giving due consideration to their morphological characters and categorizing them into textural groups systematically, and practical application in GI in urban areas could maximize the benefits. We conclude that the leaf area, petiolar length and internodal distance are the primary morphological characters that contribute to the separation of the textural groups, while hair related characters together with qualitative morphological characters such as leaf margins, leaf arrangement and prominent venation are secondary characters that contribute to defining textural groups. It is important to bear in mind that the morphological characters of plants are named and categorized by humans for our convenience. Hence, defining strict categories contributing to textural groups would always have outliers. Although our study was focused on tropical shrubs, this concept could be applied to any part of the world.

Acknowledgements

The authors are grateful to Dr. Achala Attanayake of the Royal Botanical Gardens, Peradeniya, Sri Lanka, for granting permission to collect plant material for the present research.

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