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SEED SHAPE QUANTIFICATION IN THE MALVACEAE REVEALS CARDIOID-SHAPED SEEDS PREDOMINANTLY IN HERBS

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Abstract

Martín Gómez J.J., Gutiérrez del Pozo D., Cervantes E., 2019: Seed shape quantification in the Malvaceae reveals cardioid-shaped seeds predominantly in herbs. – Botanica, 25(1): 21–31.

Seed shape in the Malvaceae and other families of the order Malvales was investigated. Seed shape was quantified by comparison with the cardioid. The *J* index is the percent similarity between both images, the seed and the cardioid, and similarity is considered in cases where the *J* index is over 90. Seed shape was analysed in 73 genera, and seeds resembling the cardioid were found in 10 genera, eight in the Malvaceae and two in the Bixaceae and Cistaceae. Seed shape was quantified by comparison with the cardioid in 105 species. A correlation was found between the values of the *J* index and plant form, with higher values of the *J* index in the seeds of herbs, intermediate – in bushes, and lower values in trees. The results suggest a relationship between seed shape and plant form, where seeds resembling the cardioid are associated with plants having small size.

Keywords: ecology, *J* index, Malvoideae, morphology, seed shape.

INTRODUCTION

The order Malvales comprises 10 families with approximately 337 genera and 6.000 species (APG, 2016). Fig. 1 (adapted from Stevens, 2001) represents the phylogenetic relationships between families in this order (APG, 2016).

Species are of cosmopolitan distribution, with many examples in tropical regions and a reduced number of species in temperate zones. Madagascar and tropical South America are rich in endemic species of this order. Tropical South America has the largest diversity of plants of any region on the Earth (Wilf et al., 2003) and places like the tropical Andes are considered one of the most important hot spots in which we can find the highest numbers of taxons in the word (Mittermeier et al., 2011; Gutiérrez et al., 2017). Attending to habit or life-form, the subfamily Malvoideae Burnett is one of the most diverse families as subshrubs in the megadiverse countries such as Ecuador (Jørgensen & León-Yánez, 1999; Neill, 2012) and in the ecosystems such as Equato-

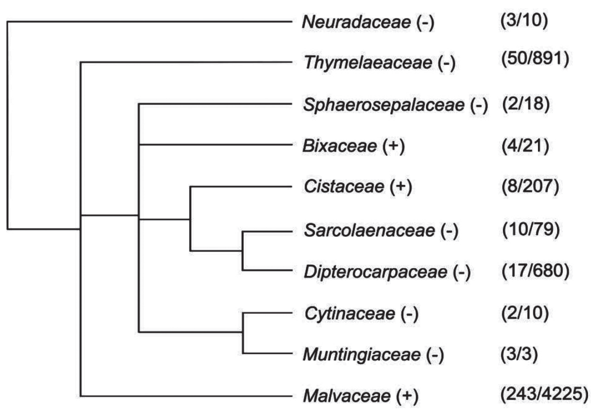

Fig. 1. Phylogenetic tree of the order Malvales showing relationships between ten families (adapted from Stevens, 2001)

rial Pacific Dry Forest. The Malvaceae Juss., *sensu lato* was the second most important family attending to the number of genera, species or endemism (Linares-Palomino et al., 2010).

The diversity of life forms including trees as well as shrubs, herbs and parasitic plants makes this order interesting for the investigation of the relationship of seed shape with plant ecology, structure and life cycle. In particular, we aimed to investigate whether cardioid shaped seeds were more frequent in herbs than in trees.

The Malvaceae is the largest family in this order including now the old families of Bombacaceae Kunth, most of the Sterculiaceae Vent. and Tiliaceae Juss., constituting the core Malvales (Bayer et al., 1999) with 243 genera and more than 4.225 species, some of these of economic importance, such as cacao, cotton, durian and okra as well as ornamentals such as *Malva* Tourn. Ex. L. (mallow) and *Lavatera* L. (tree mallow). The genera with higher number of species are *Hibiscus* L. (300 species), *Sterculia* L. (250 species), *Dombeya* Cav., *Pavonia* Ruiz and *Sida* L. (with more than 200 species each; Judd et al., 2008). *Dombeya* is not native to South America, but to tropical Africa and the Mascarenes, where about 200 species have been recorded (Prota, 2008).

Seed shape is an interesting criterion for taxonomy, and it has been used for example in the Caryophyllaceae (Minuto et al., 2006; Sukhorukov et al., 2015; Dadandi & Yildiz, 2015) and in the Orchidaceae (Clifford & Smith, 1969). The application of morphology to classification requires quantification. In recent years we have established a method for seed shape quantification based on the comparison of seed images with geometrical figures (Cervantes et al., 2010, 2012, 2016). In some plant species, seed images give high percent of similarity with simple geometrical figures such as the ellipse, ovoid and cardioid allowing seed shape quantification for comparative purposes.

The method of seed shape quantification has been first applied to seeds of *Arabidopsis thaliana* (L.) Heynh. (Cervantes et al., 2010) as well as to model legumes *Lotus japonicus* (Regel) K. Larsen, and *Medicago truncatula* Gaertn. (Cervantes et al., 2012) and seeds in other plant families such as *Capparis spinosa* L. in the Capparaceae Juss. (Saadaoui et al., 2013), *Jatropha curcas* L. and *Ricinus comunis* L. in the Euphorbiaceae Juss. (Saadaoui et al., 2015; Martín-Gómez et al., 2016), *Rhus tripartita* DC in the Anacardiaceae R. Br. (Saadaoui et al., 2017) and *Olea europaea* L. (Oleaceae Hoffmanns. & Link; Hannachi et al., 2017). Recently, the method has been applied to the analysis of seed shape variation in the order *Cucurbitales* Dumort. (Cervantes & Martín Gómez, 2018). The hypothesis of depart based on previous work is that there is a correlation between seed morphology and plant form, in which small plants with rapid life cycles such as the model systems *Arabidopsis*, *Lotus* and *Medicago* have seeds more related to the cardioid than larger, more complex plants in their families. To investigate further this relationship we present here an overview of seed shape in the Malvaceae quantifying seed shape in diverse genera and species of this family by comparison with the cardioid. The Malvaceae contains herbs, shrubs and trees. The diverse life forms in the family allow investigating the relationship between seed shape and plant form.

MATERIALS AND METHODS

Seed image analysis

Seed images were obtained from seed image databases and photographs from our seed collections at IRNASA-CSIC (Salamanca, Spain) and Ecuadorian Amazon Herbarium (ECUAMZ) located at Postgraduate Research Centre for Amazon Conservation (Napo, Ecuador). Tables 1 and 2 contain the sources of information related respectively to plant form and the sources for the seed images analysed in Tables 3 and 4. In addition, seeds of *Cochleospermum vitifolium* and *Helianthemum chamaecistus* were obtained from Universidad Nacional Autónoma de México (CIEco) (http://www.oikos.unam.mx/) and Herbarium (PE) Institute of Botany, Chinese Academy of Sciences (http://pe.ibcas.ac.cn/).

Image analysis

The cardioid was the geometric figure used as model for the comparison and quantification of seed shape. Composed images containing the cardioid and each seed were elaborated using the software image Corel PHOTO-PAINT X7. Quantification of areas was done with Image J (Java Image Processing Program).

Table 1. Sources of the information contained in Tables 3 and 4, related to plant form

Flora of Israel Online	http://flora.org.il/en/plants/
Australian Tropical Rainforest Plants	http://keys.trin.org.au/key-server/player.jsp?keyId=41
Kewscience Plants of the world online	http://powo.science.kew.org
Useful Tropical Plants	http://tropical.theferns.info
eFloras	http://www.efloras.org
FLORA ARGENTINA	http://www.floraargentina.edu.ar
GREEN PLANET	http://www.greenplanet.co.za
MALVACEAE INFO	http://www.malvaceae.info
Missouri Botanical Garden	http://www.missouribotanicalgarden.org
Tropicos	http://www.tropicos.org
Conservatoire et Jardin botaniques Ville de Genève	http://www.ville-ge.ch/musinfo/bd/cjb/
Wikipedia	https://es.wikipedia.org
FloraBase the Western Australian Flora	https://florabase.dpaw.wa.gov.au
India Biodiversity Portal	https://indiabiodiversity.org
United State Department of Agriculture	https://plants.sc.egov.usda.gov
Seeds of South Australia	https://spapps.environment.sa.gov.au/seedsofsa/
VICFLORA Flora of Victoria	https://vicflora.rbg.vic.gov.au
Plant Resources of Tropical Africa Fund. Wageningen PROTA4U web database	https://www.prota4u.org/database/

Table 2. Sources of the information contained in Tables 3 and 4, related to the origin of seed images analysed

1	USDA-NRCS PLANTS Database: National Plant Data Team, Greensboro, NC 27401-4901 USA	http://plants.usda.gov; http://www.ars-grin.gov/~sbmljw/images.html
2	Seeds of South Australia	http://saseedbank.com.au/
3	Pflanzenfotos von Stefan Lefnaer	http://flora.lefnaer.com
4	Muséum Toulouse	https://www.museum.toulouse.fr/el-museo
5	Universidad Nacional Autónoma de México (CIEco)	http://www.oikos.unam.mx/muestras/5.
6	Herbarium (PE) Institute of Botany, Chinese Academy of Sciences	http://pe.ibcas.ac.cn/
7	Herbarium of IRNASA-CSIC. Salamanca	http://www.irnasa.csic.es/imagenes-de-semillas
8	Kew Royal Botanic Garden	http://data.kew.org
9	Agro slide bank	http://asb.com.ar/
10	The Ohio state University	http://www.oardc.ohio-state.edu/seedid/
11	Malvaceae Info	http://www.malvaceae.info/Genera/gallery.html

To obtain the J index, the areas in two regions were compared: the regions shared by the model and the seed image (common region, C) and the regions not shared between both areas (D). The index of adjustment (J index) was defined by: J = (area C) / (area C + area D) × 100, where C represents the common region and D the regions not shared (Fig. 2). J is a measure of seed shape, not of its area. It ranges between 0 and 100 decreasing, when the size of the non-shared region grows and equals 100, when the geometric model and the seed image areas coincide, i.e. when area (D) is zero. Similarity was considered, when the J index values were over 90.

The geometric figure used as a model was the cardioid, and the values of the J index given for each species were the means of measurements done on different seed images (between one and twelve seed images per species; the number of images used per each species is indicated in Tables 3 and 4). Seed shape was analysed in 10 families of the order *Malvales*. The number of genera (and species) observed were: Bixaceae Link, 3 (4); Cistaceae Juss., 8 (70); Malvaceae, 52 (118); Neuradaceae Kostel, 1 (1), Thymelaceae Juss., 5 (43), Sphaerosepalaceae Warb. Tiegh. ex Bullock, 1 (1), Sarcolenaceae Caruel, 1 (1), Dipterocarpaceae Blume, 4 (18), Cytinaceae A. Rich., 1 (1) and Muntingiaceae Bayer, Chase & Fay, 1 (1).

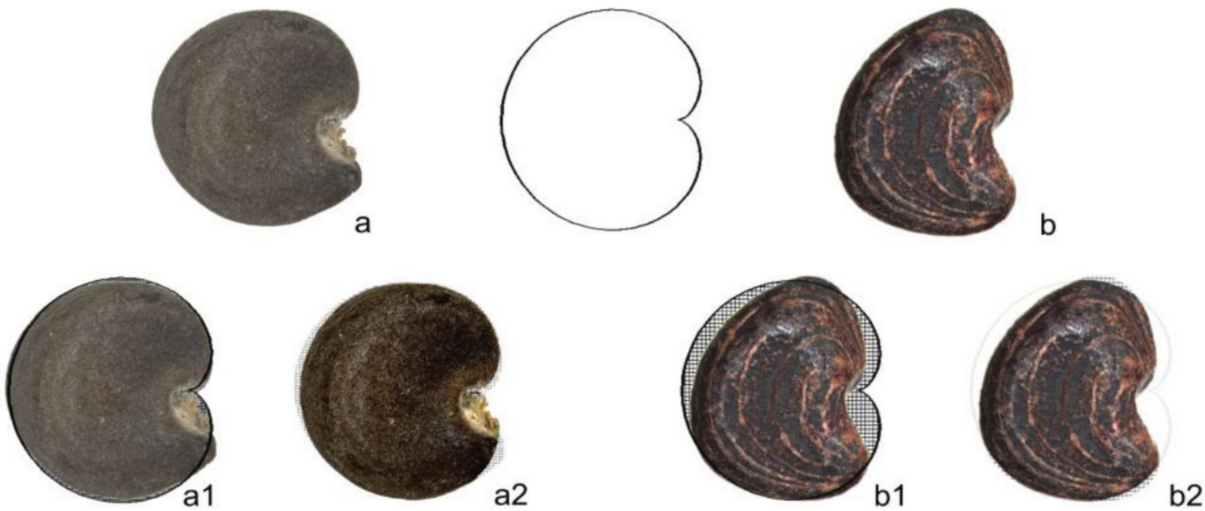

Fig. 2. Two examples of the method used to calculate the *J* index. The image presents the cardioid (top, centre) and the examples of seeds of *Malva weinmanniana* (left) and *Hibiscus panduriformis* (right) giving values of the *J* index, respectively 93.5 and 84.6. Images in a1 and b1 show total area, while a2 and b2 show the area shared between seed image and the cardioid. The *J* index is the ratio between shared and total ×100. Similarity is considered when the *J* index is over 90

Statistical analysis

Mean values of the *J* index were compared by ANOVA (IBM SPSS statistics v25) between three groups of species according to their life form (trees, shrubs and herbs) as well as between the two groups of subfamilies in the Malvaceae (Malvoideae and others).

RESULTS

Seed images adjusting to cardioid models (the *J* index values superior to 90) were found in three of the families: Bixaceae (cardioid detected in one out of three genera observed), Cistaceae (cardioid detected in one out of eight genera observed), and Malvaceae (cardioid detected in eight out of 52 genera observed).

In the Bixaceae, with a total of four genera and 21 species, seeds were observed in four species: *Amoreuxia wrightii* A. Gray, *Bixa orellana* L., *Cochlospermum orinocense* (Kunth) Steud., and *Cochlospermum vitifolium* (Willd.) Spreng. Similarity to a cardioid was detected in *Cochlospermum vitifolium* (Fig. 3, left). In the Cistaceae, with eight genera and 207 species, seeds were observed in all genera (*Cistus* L.*, Fumana* (Dunal) Spach, *Halimium* (Dunal) Spach, *Helianthemum* Gray, *Hudsonia* L., *Lechea* Kalm ex L., *Tuberaria* (Dunal) Spach, and *Xolantha* Raf.) and similarity to cardioid was detected in seeds of *Helianthemum chamaecistus* Mill. (Fig. 3, right).

Fig. 3. Seeds of *Cochlospermum vitifolium* (Bixaceae; left) and *Helianthemum chamaecistus* (Cistaceae; right). Values of the *J* index are indicated. Bar equals 0.5 mm

In the Malvaceae, seed shape was investigated in a total of 52 genera (118 species) and similarity to the cardioid was detected in eight genera of these. In Tables 3 and 4, the results are presented by subfamilies.

Seeds observed in eight subfamilies (Bombacoideae, Brownlowioideae, Byttnerioideae, Dombeyoideae, Grewioideae, Helicteroideae, Sterculioideae, Tilioideae) did not present similarity to a cardioid. Most of species in these eight subfamilies were trees or shrubs and the values of the *J* index are presented in Table 3.

In contrast, life forms in the subfamily Malvoideae were predominantly herbs and shrubs and seeds

Table 3. Plant life form and the *J* index in the subfamilies of the Malvaceae excluding the Malvoideae

Subfamily	Species	Life form	*J* index (seed number)	Source of seed analysed
Bombacoideae	*Adansonia digitata* L.	Tree (Baobab)	79.1 (1)	1
Bombacoideae	*Ceiba aesculifolia* (Kunth) Britten and Baker f.	Tree	70.3 (1)	1
Bombacoideae	*Pseudobombax grandiflorum* (Cav.) A.Robyns	Tree	85.7 (1)	1
Bombacoideae	*Septotheca tessmannii* Ulbr.	Tree	50.0 (1)	1
Brownlowioideae	*Berrya pacifica* A.C.Sm.	Tree	71.5 (1)	1
Byttnerioideae	*Abroma augustum* (L.) L.f.	Shrub	55.2 (1)	1
Byttnerioideae	*Guazuma ulmifolia* Lam.	Tree	69.2 (3)	1
Byttnerioideae	*Hermannia muricata* Eckl. and Zeyh.	Herb or small shrub	87.7 (1)	8
Byttnerioideae	*Theobroma cacao* L.	Tree	67.4 (2)	1
Dombeyoideae	*Dombeya tiliacea* (Endl.) Planch.	Tree	65.0 (1)	1
Grewioideae	*Corchorus olitorius* L.	Herbs, perennial or annual	78.0 (2)	1
Grewioideae	*Erinocarpus nimmonii* J.Graham	Tree	68.0 (2)	1
Grewioideae	*Grewia flavescens* Juss	shrub	81.3 (1)	8
Grewioideae	*Grewia villosa* Willd.	shrub	86.2 (3)	8
Grewioideae	*Triumfetta rhomboidea* Jacq.	Herbs, perennial or annual, sub-shrub	79.0 (3)	1
Helicteroideae	*Durio zibethinus* L.	Tree	66.0 (1)	1
Helicteroideae	*Helicteres baruensis* Jacq.	Shrub	65.7 (1)	1
Sterculioideae	*Brachychiton* Schott and Endl.	Tree	62.7 (2)	7
Sterculioideae	*Cola acuminata* (P.Beauv.) Schott and Endl.	Tree	87.6 (1)	1
Sterculioideae	*Franciscodendron laurifolium* (F.Muell.) B.Hyland and Steenis	Tree	68.0 (1)	1
Sterculioideae	*Pterygota excelsa* (Standl. and L.O.Williams) Kosterm.	Tree	55.1 (1)	1
Sterculioideae	*Sterculia setigera* Delile	Tree, shrub*	68.1 (4)	8
Sterculioideae	*Sterculia urens* Roxb.	Tree, shrub*	56.0 (2)	1
Tilioideae	*Apeiba membranacea* Spruce ex Benth.	Tree	70.2 (8)	
Tilioideae	*Tilia mandshurica* Rupr. and Maxim.	Tree	79.1 (1)	1

of species in this subfamily had higher values of the *J* index (Table 4). This is associated with resemblance to a cardioid in a larger number of genera. Seeds of eight genera gave similarity to the cardioid: *Abelmoschus* Medik., *Abutilon* Mill., *Althaea* L., *Hibiscus* L., *Iliamna* Greene, *Kosteletzkya* C. Presl, *Malva* Tourn. ex L., and *Malvastrum* A. Gray (Fig. 4).

Seeds of other species resembled cardioid or modified cardioids giving the *J* index values close to 90, but did not reach this threshold value: *Abutilon lignosum* (Cav.) G. Don, *Althaea ludwigii* L., *Anoda cristata* (L.) Schltdl., *Fuertesimalva peruviana* (L.) Fryxell, *Hibiscus trionum* L., *Malvastrum coromandelianum* (L.) Garcke, *Modiola caroliniana* (L.) G.Don, *Sphaeralcea bonariensis* (Cav.) Griseb.

Seeds of the species in other genera resembled different geometrical figures (mainly ellipse and ovoid). The results were not quantified using these models. The *J* index was always calculated with the cardioid.

Comparison of the mean *J* index values between Malvoideae and the other subfamilies revealed differences with higher values in the Malvoideae (mean Malvoideae = 83.80; mean other subfamilies = 70.91; significance at $p = 0.001$). Comparison of the mean *J* index values between species grouped in three classes according to their life forms (trees, shrubs, herbs) revealed differences with the higher *J* index values in herbs, intermediate in shrubs and lower in trees (Table 5).

DISCUSSION

Seed shape is an important factor in plant taxonomy and ecology and also may be useful for mutant phenotyping (Tanabata et al., 2012) as well as in

Table 4. Seeds resembling the cardioid and the *J* index values in the subfamily Malvoideae. Number of seeds observed for each species is indicated between parentheses

Species	Life form	*J* index (seed number)	Source of seed analysed
Abelmoschus Medik.			
Abelmoschus esculentus (L.) Moench	Annual herb	92.4 (2)	1
A. moschatus Medik.	Perennial herb	90.2 (3)	1
Abutilon Mill.			
A. abutiloides (Jacq.) Garcke ex Hochr.	Subshrub	85.3 (4)	6
A. angulatum (Guill. and Perr.) Mast.	Subshrub	86.8 (4)	8
A. incanum (Link) Sweet	Subshrub	90.2 (3)	1
A. indicum (L.) Sweet	Shrub	79.9 (2)	6
A. mollicomum (Willd.) Sweet	Subshrub, Shrub	81.8 (4)	1
A. otocarpum F.Muell.	Shrub	80.2 (4)	2
A. theophrasti Medik.	Annual herb	86.7 (9)	1
Althaea L.			
A. cannabina L.	Perennial herb	92.8 (9)	4
Anoda Cav.			
A. cristata (L.) Schltdl.	Annual herb	87.9 (2)	1
Callianthe Donnell			
C. pauciflora (A.St.-Hil.) Dorr	Annual or perennial herb	87.8 (6)	9
C. peruviana (Lam.) Dorr	Shrub	86.6 (4)	6
Callirhoe Nutt.			
C. digitata Nutt.	Perennial herb	84.5 (4)	1
C. involucrata (Torr. and A.Gray) A.Gray	Perennial herb	86.1 (4)	1
Decaschistia Wight and Arn.			
D. crotonifolia Wight and Arn	Shrub	84.8 (1)	1
Fuertesimalva Fryxell			
F. peruviana (L.) Fryxell	Annual herb	88.8 (3)	1
Gossypium L.			
G. arboreum L.	Shrub	65.1 (1)	1
G. barbadense L.	Shrub	65.3 (1)	1
G. hirsutum L.	Annual herb	66.6 (1)	1
Hibiscadelphus Rock			
H. giffardianus Rock	Trees	80.0 (1)	1
Hibiscus L.			
H. cannabinus L.	Annual herb	83.9 (3)	1
H. coccineus Walter	Herb perennial	85.9 (6)	1
H. krichauffianus F.Muell.	Shrub	84.1 (3)	2
H. moscheutos L.	Herb perennial	87.2 (3)	1
H. panduriformis Burm.f.	Annual herb	84.6 (1)	8
H. rhabdotospermus Garcke	Annual herb	82.2 (5)	8
H. solanifolius F.Muell.	Shrub	81.5 (3)	2
H. sturtii Hook	Perennial subshrub	80.3 (3)	2
H. syriacus L.	Shrub	85.2 (2)	1
H. tiliaceus L.	Tree	82.7 (3)	1
H. trionum L.	Annual herb	89.4 (9)	1
H. verdcourtii Craven	Shrub	91.5 (1)	2
Iliamna Greene			
I. remota Greene	Perennial herb	86.6 (4)	11
I. rivularis (Douglas) Greene	Perennial herb	91.0 (5)	1
Kitaibela Willd.			
K. vitifolia Willd.	Perennial herb	82.9 (4)	6
Kokia Lewton			
Kokia drynarioides (Seem.) Lewton	Tree		1
Kosteletzkya C.Presl			
Kosteletzkya pentacarpos (L.) Ledeb.	Perennial herb	90.2 (2)	1
Lawrencia Hook.			
*L. berthae (*F.Muell.) Melville	Subshrub	79.0 (2)	2
L. spicata Hook.	Herb	72.9 (1)	2
L. squamata Nees	Shrub	78.4 (3)	2
Malacothamnus Greene			
M. fasciculatus (Nutt.) Greene	Shrub	73.3 (4)	1
Malva Tourn. ex L.			
M. assurgentiflora (Kellogg) M.F.Ray	Shrub	85.7 (5)	1
M. ludwigii (L.) Soldano, Banfi and Galasso	Annual herb	88.3 (4)	8
M. moschata L.	Perennial herb	91.1 (1)	3
M. neglecta Wallr.	Perennial herb	88.8 (6)	1
M. parviflora L.	Annual herb	87.9 (1)	1
M. preissiana Miq.	Perennial herb	85.9 (2)	2

Species	Life form	*J* index (seed number)	Source of seed analysed
M. pusilla Sm.	Annual or biennial herb	89.0 (1)	10
M. setigera K.F.Schimp. and Spenn.	Annual herb	90.1 (4)	4
M. sylvestris L.	Annual or perennial herb	92.7 (12)	7
M. thuringiaca (L.) Vis.	Perennial herb	91.3 (6)	1
M. verticillata L.	Annual herb	89.0 (3)	1
M. weinmanniana (Besser ex Rchb.) Conran	Shrub	92.8 (2)	2
Malvastrum A.Gray			
M. americanum (L.) Torr.	Perennial herb	71.0 (4)	1
M. coromandelianum (L.) Garcke	Annual or perennial herb	86.7 (3)	9
M. hispidum (Pursh) Hochr.	Annual herb	92.0 (4)	1
Malvella Jaub. and Spach			
M. leprosa (Ortega) Krapov.	Perennial herb	83.5 (2)	10
Modiola Moench			
M.caroliniana (L.) G.Don	Annual or perennial herb	84.9 (6)	1
Napaea L.			
N. dioica L.	Perennial herb	87.5 (1)	1
Pavonia Cav.			
P. hastata Cav.	Perennial herb	73.0 (4)	1
Radyera Bullock			
R. farragei (F.Muell.) Fryxell and S.H.Hashmi	Shrub	69.2 (2)	2
Sida L.			
S. acuta Burm.f.	Annual or perennial herb	79.3 (6)	1
S. cordifolia L.	Annual or perennial herb	78.3 (2)	8
S. rhombifolia L.	Annual or perennial herb	78.5 (3)	9
S. santaremensis Monteiro	Annual or perennial herb	83.4 (1)	9
S. spinosa L.	Annual or perennial herb	83.3 (1)	9
S. trichopoda F.Muell.	Annual or perennial herb	81.0 (2)	2
S. platycalyx F.Muell. ex Benth.	Annual or perennial herb	84.7 (3)	2
Sidalcea A.Gray ex Benth.			
S. neomexicana A.Gray	Perennial herb	86.0 (5)	1
S. Oregana (Nutt.) A.Gray	Perennial herb	79.1 (3)	1
Sphaeralcea A. St.-Hilaire			
S. ambigua A.Gray	Perennial herb	83.9 (2)	1
S. angustifolia (Cav.) G.Don	Perennial herb	85.5 (5)	1
S. bonariensis (Cav.) Griseb.	Perennial herb	85.9 (6)	9
S. coccinea (Nutt.) Rydb.	Perennial herb	82.7 (4)	1
Sphaeralcea fendleri A.Gray	Perennial herb	88.0 (5)	1
Thespesia Sol. ex Corrêa			
T. populnea (L.) Sol. ex Corrêa	Shrub	74.0 (4)	1
Urena Dill. ex L.			
U. lobata L.	Perennial herbs	74.5 (3)	1

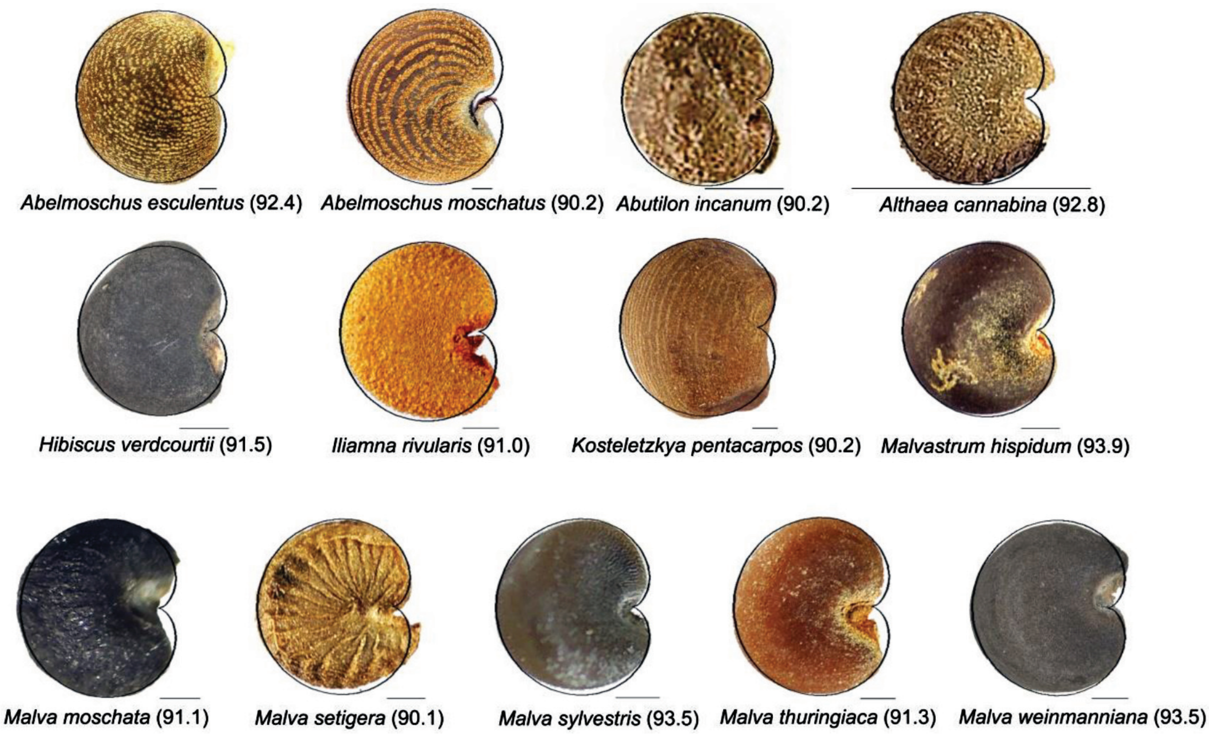

Fig. 4. Seeds of species of the genus *Abelmoschus*, *Abutilon*, *Althaea, Hibiscus*, *Iliamna*, *Kosteletzkya Malvastrum* and *Malva* gave the *J* index over 90. Bar equals 0.5 mm

Table 5. The comparison of *J* index values in three groups of species of the Malvaceae based on their life forms (trees, shrubs, herbs)

Plant form	Number of species	Standard deviation	Maximum value	Minimum value	Mean values of the subsets different at p = 0.05		
Trees	20	10.0	87.6	50.0	70.1		
Shrubs	26	9.2	92.8	55.2		79.6	
Herbs	56	5.7	92.8	66.6			84.9

the description of plant responses to biotic and abiotic stress (Jamil et al., 2017). Shape in biological objects is often described based on automated methods of boundary analysis such as Fourier descriptors (Gonzalez & Woods, 2007; Sethares, 2012), but seed shape is related to geometric figures and for quantification it is possible to compare the outline of an image with geometric models giving the result in the form of percent of similarity with this figure. For this purpose, the cardioid, ellipse and ovoid figures are used to describe well the shapes of seeds (Cervantes et al., 2016).

The cardioid is the curve generated by a point of a circle rolling over another circle of the same radius (Rangel-Mondragón, 2011). In biology, many structures resemble the cardioid, because it represents the image of a body growing from a point of insertion, static (Thompson, 1992). Often different geometrical figures may fit the outline of the seed images in a given taxonomical group, for example, in the Ranunculales we have observed seeds resembling the ovoid, cardioid, ellipse and other figures (Martín Gómez et al., submitted).

The Malvaceae constitute an interesting model to investigate the relationships between life form and seed shape, because the family contains a diversity of life forms. Species of the Malvaceae do not constitute the dominant form in many ecosystems, but they are in the Equatorial Pacific region located in western Ecuador and north-western Peru, where the Bombacoideae subfamily constitutes a great component of the woody vegetation (Gentry, 1993; Linares-Palomino et al., 2010).

Comparison of the *J* index values in diverse species of the Malvaceae allowed testing our hypothesis of a relationship between life form and similarity to the cardioid in the seeds for this family. The greatest resemblance of seeds to a cardioid was found in herbs, whereas the comparison between life form showed reduced values of the *J* index in trees. Among the subfamilies of Malvaceae, only the subfamily Malvoideae presented most herbaceous species. Out of 77 species analysed in this subfamily, 53 were herbs and 24 – shrubs or trees. Woody species in this family presented lower values of the *J* index. The correlation between herbaceous form and seed shape similarity to the cardioid figure has been previously reported in the family Anacardiaceae, of the order Sapindales (Saadaoui et al., 2017) as well as the Papaveraceae Juss. in the Ranunculales (Martín Gómez et al., *in press*).

The subfamilies Sterculioideae, Tilioideae, Bombacoideae, Brownlowioideae and Dombeyoideae contain shrubs or trees of tropical distribution. While only species in the genus *Tilia* (Tilioideae) grow in temperate environments of the northern hemisphere (Richardson et al., 2015), nine species of the Bombacoideae contribute to the Ecuatorian and Peruvian Seasonal Dry Forest (SDF). It may be interesting to investigate seed morphology in these species. A high rate of diversification in Malvoideae has been attributed to numerous carpels and to their schizocarp structure (Areces-Berazain & Ackerman, 2017), but also the herbaceous form together with cardioid resembling seeds may have played a role in the diversification of the subfamily Malvoideae, allowing their colonization during the Tertiary and Quaternary Eras of larger regions of the planet. These hypotheses need to be evaluated in other botanical groups combining quantitative structural studies with other data from paleobotany and molecular phylogenetics.

The authors declare there is no conflict of interest.

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MALVACEAE SĖKLŲ FORMOS VERTINIMAS ATSKLEIDĖ ŠIRDIŠKOS FORMOS SĖKLŲ DOMINAVIMĄ ŽOLINIUOSE AUGALUOSE

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Santrauka

Buvo tirta Malvaceae ir kitų Malvales šeimų augalų sėklų forma. Sėklos buvo vertinamos pagal jų atitikimą taisyklingai širdiškai formai. Atitikimas tarp dviejų formų buvo įvertintas naudojant *J* indeksą, išreiškiantį jų panašumą procentais ir yra reikšmingas, jei > 90 proc. Buvo analizuotos 105 augalų rūšių, priklausančių 73 gentims, sėklos. Širdiškos formos sėklos buvo nustatytos dešimtyje genčių, tarp kurių aštuonios priklausė Malvaceae ir dvi Bixaceae ir Cistaceae šeimoms. Nustatytas *J* indekso ryšys su augalų gyvenimo forma. Žolinių augalų sėklos turėjo didesnį *J* indeksą, krūmų – vidutinį, o medžių sėklos mažiausias *J* indekso vertes. Rezultatai parodė ryšį tarp sėklų formos ir augalų formos, širdiškos formos sėklos dažnesnės tarp žolinių augalų ir krūmų.