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SEED MORPHOMETRY OF SELECTED PLANT SPECIES FROM BROMO TENGGER SEMERU NATIONAL PARK, EAST JAVA, INDONESIA: THE SIGNIFICANCE IN IDENTIFICATION AND DISPERSAL

Dewi Ayu LESTARI[1,*], Elga RENJANA[1], Linda Wige NINGRUM[2], Apriyono RAHADIANTORO[1], Elok Rifqi FIRDIANA[1], TRIMANTO[2], Shofiyatul MAS'UDAH[1], Lia HAPSARI[1], Dian LATIFAH[1]

[1] Research Center for Applied Botany, National Research and Innovation Agency (BRIN), Jalan Raya Bogor KM 46 Cibinong, Bogor, 16911, West Java, Indonesia.

[2] Research Center for Ecology and Ethnobiology, National Research and Innovation Agency (BRIN), Jalan Raya Bogor KM 46 Cibinong, Bogor, 16911, West Java, Indonesia

Abstract

Seed morphological characters assessed through morphometry, include both qualitative and quantitative parameters. These are crucial for supporting taxonomic identification and classification processes, as well as predicting traits related to seed dispersal strategies. This study aimed to identify the most influential morphometric characters for classifying seed types and their dispersal strategies. Seeds from 12 selected species, collected during a plant exploration at Bromo Tengger Semeru National Park (BTSNP), were analyzed. Measurements include seed length, width, thickness, weight, volume, and hilum size, along with observations of seed color, texture, and shape to calculate the Eccentricity Index (EI) and Flatness Index (FI). Data were analyzed using Principal Component Analysis (PCA) and cluster analysis in PAST ver.4.04. The results revealed two seed groupings of species associated with M. acuminata from BTSNP based on morphometric influences: Group I, influenced by weight, color, hilum size, shape, texture, and EI value; and Group II: influenced by length, width, thickness, volume, and FI value. Overall, quantitative characters were more influential than qualitative ones in identifying the seeds of the 12 species studied. Thus, numerical characters serve as valuable supporting features for species grouping. Additionally, most seeds from the 12 species are likely dispersed by animals.

***Keywords**: Bromo Tengger Semeru National Park; Identification; Morphometry; Seed; Supporting characters*

Introduction

Seeds play a crucial role in plant regeneration and dispersal [1]. In the study of taxonomy and plant identification, seed morphological characters are essential especially for young taxonomists in the seed plant's introduction [2] as well as the characterization of certain species [3, 4]. In addition, they are also related to biological and ecological processes, such as dormancy, dispersal, germination and adaptation of seeds to the surrounding environment [5-7]. The scope of seed morphological characters is enormous with various uniqueness and variations. Qualitative characters such as texture, color and shape of seeds vary widely likewise the quantitative characters such as seed size, which include length, width, thickness and weight.

* Corresponding author: chunyang.dee@gmail.com

These variations are useful as criteria to distinguish between wild plants and cultivars produced by the plant domestication [8].

The numerical morphological characters can be analyzed through morphometry. Morphometric characters can contribute to support identification up to the genera level, even at the species and intraspecies level [9]. Furthermore, it is evidenced that those characters correlate with germination and seed viability tests in seed conservation efforts [10].

Morphometry is also applicable to determine the qualitative and quantitative characters of the seed. As a form of ecological adaptation, many seed characters become valuable and favorable traits to survive the natural selection in its dispersal capability, as a form of ecological adaptation. Seed size, for instance, becomes the more consistent predictor of seed dispersal compared to the climate. The big seeds are always dispersed by animal, or zoochory and not wind-dispersed [7, 11, 12].

Bromo Tengger Semeru National Park (BTSNP) is one of the National Parks in East Java Province, Indonesia. Geographically, it is located between S 7°54’-8°13’ and E 112°51’-113°04’ with an altitude range of 750-3676 m asl and has three types of ecosystems, i.e., sub-montane, montane and sub-alpine [13]. With a total area of 50,276.2 hectares and varied topography, BTSNP has a diversity of plants reaching 1025 species [14].

In 2020, we carried out a seed conservation expedition in BTSNP (Fig. 1) and discovered some of selected plant species were fruiting.

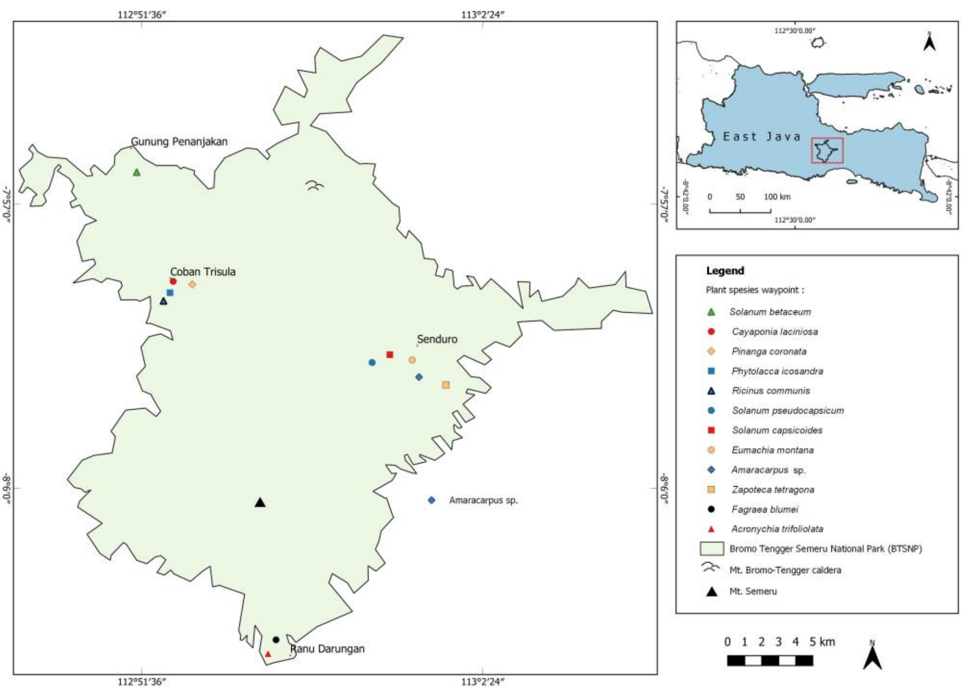

Fig. 1. Study sites to collect the seed materials in BTSNP

Those plants are wild, interact and associate with other plant species in a plant community, and have potential uses. Such collecting activity, especially seeds of selected high-value plant species, is one of the conservation efforts notably in seed conservation for long-term storage through seed banking [15, 16]. The collected seeds certainly must represent the germplasm diversity of population, seed quality and natural seed dispersal mechanism [17].

This study aimed to determine the most influential morphometric characters in identifying the types of selected seeds found in the primary forest area of BTSNP along with seed dispersal strategy from each species. The detailed information obtained is expected to provide a reference for the species identification of seed morphology related to seed conservation.

Experimental part

Study area

This study was carried out from November 2020 to April 2021 at the Laboratory and Seed Bank of Purwodadi Botanic Gardens – National Research and Innovation Agency (BRIN), Pasuruan, East Java, Indonesia. The seed materials were obtained from a field study in BTSNP covering the area of Lumajang – Malang – Pasuruan – Probolinggo Regencies (East Java, Indonesia), with the location shown in Fig. 1.

Materials

The materials studied were seeds of 12 selected plant species from BTSNP, comprised of *Acronychia trifoliolata*, *Amaracarpus* sp., *Cayaponia laciniosa*, *Eumachia montana*, *Fragaea blumei*, *Phytolacca icosandra*, *Pinanga coronata*, *Ricinus communis*, *Solanum betaceum*, *S. capsicoides*, *S. pseudocapsicum*, and *Zapoteca tetragona* (Fig. 2). These species were found fruiting in four BTSNP resorts, namely Coban Trisula, Mount Penanjakan, Ranu Darungan, and Senduro during plants exploration in October to November 2020 [18].

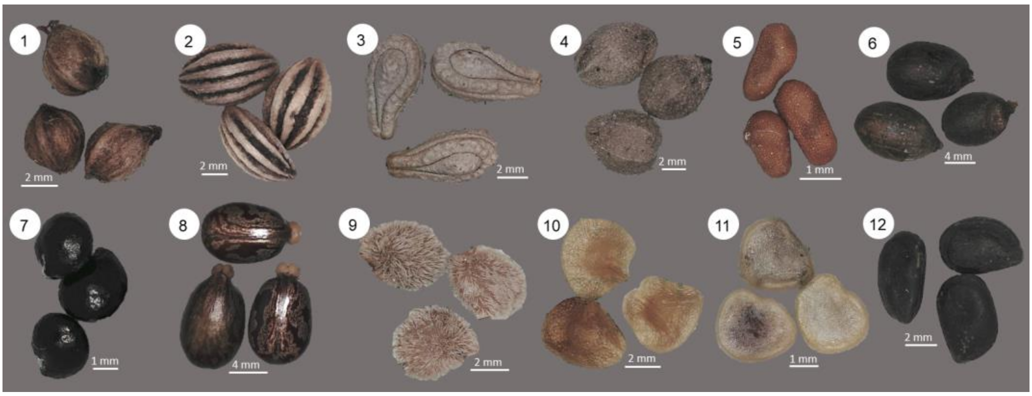

Fig. 2. The seed materials from BTSNP:
1. *Acronychia trifoliolata;* 2. *Amaracarpus* sp.; 3. *Cayaponia laciniosa;* 4. *Eumachia montana;* 5. *Fragaea blumei;* 6. *Pinanga coronata;* 7. *Phytolacca icosandra;* 8. *Ricinus communis;* 9. *Solanum betaceum;* 10. *S. capsicoides;* 11. *S. pseudocapsicum;* 12. *Zapoteca tetragona*

Methods

About 50 seed specimens of each species were randomly sampled for observation and morphometric analysis. The morphological characters observed including quantitative characters (seed length, width, thickness, weight, volume, and hilum size) as well as qualitative characters (seed color, texture/surface, and shape), Eccentricity Index (EI; Equation 1), and Flatness Index (FI; Equation 2). EI is the ratio between seed length and width that serves to estimate the seed shape, while FI is calculated to determine the level of seed surface flatness. EI and FI values are closely related to seed shape [19, 20]. The seed length, width, thickness and hilum size were measured using a digital caliper (Krisbow KW 06-351), while seed weight was measured using an analytical balance (Denver Instrument TB-224). The calculation of seed volume refers to *Ganhao & Dias* [21], while the characterization of seed color, surface, and shape refers to *Lestari* [22]. Qualitative data were converted into quantitative data using a scoring method (Table 1).

Table 1. Scoring of seed qualitative characters of 12 plant species from BTSNP.

Qualitative characters	Scoring	
Color	1 = grey 2 = cream 3 = yellowish white 4 = golden yellow 5 = pale brown 6 = pale brown with dark brown	7 = pale brown with black 8 = brown 9 = dark brown 10 = dark brown with cream pattern 11 = dark brown with pale brown pattern 12 = black
Texture	1 = smooth and shiny 2 = pubescent, cream color hairs 3 = rough 4 = rough with pattern	5 = rough and notched 6 = rough and stringy 7 = rough (like cracks) 8 = ribbed and stringy
Shape	1 = plateriform 2 = cuneiform 3 = elliptic 4 = broad elliptic 5 = oblong 6 = ovoid	7 = broad ovoid 8 = fusiform 9 = semi-deltoid 10 = narrow square 11 = broad kidney 12 = spheroid

$$Eccentricity\ Index = \frac{seed\ length}{seed\ width} \quad (1)$$

$$Flatness\ Index = \frac{seed\ length + seed\ width}{2\ x\ seed\ thickness} \quad (2)$$

Data analysis

The seed morphometric data were tabulated in Microsoft Excel for further analysis. The summary of the distribution of quantitative seed character data was presented graphically in a boxplot, meanwhile, the qualitative data were presented in a table and described descriptively. Further, the morphometric data were subjected to Principal Component Analysis (PCA) and clustering analysis using PAST ver. 4.04 statistical program [23]. The qualitative data were converted into numeric values (1, 2, 3, …, n) before analysis. Multivariate ordination PCA was performed using a correlation matrix and the results were shown in a scatter biplot between groups, two-way multivariate clustering analysis was performed using UPGMA algorithm with Bray-Curtis similarity index and 1000 bootstrapping. PCA was used to determine the most important morphometric characters in morphological identification and to reduce the dimensionality of morphometric data, while two-way cluster analysis was used to determine the species grouping and to identify the contribution of morphometric characters to the grouping. The prediction of seed dispersal was determined based on morphometric characters [24-26].

Results and discussion

Variation of qualitative and quantitative characters of the seed morphometry

The seed morphological qualitative characters of 12 plant species from BTSNP are shown in Table 2. The qualitative-specific trait of Rubiaceae seeds from BTSNP, such as *Amaracarpus* sp. and *Eumachia montana,* is the lengthwise groove on their surface. This is relevant to a statement from *Rafferty* [27] regarding *Coffea charrieriana* seed morphology. The seed shape of *Galium* spp., another example of Rubiaceae, varies from cylindrical or globose, globose to sub-globose or reniform. The seed colors are of less diagnostic and systematic value among species in Rubiaceae because of the narrow range of color degrees between species [28]. A combination of seed morphology from *Hamelieae* (Rubiaceae) results in a taxonomic value through unequivocal delineation of the genera, such as seed shape and color [29]. Seeds from Solanaceae, such as *Solanum betaceum*, *S. capsicum* and *S. pseudocapsicum*, have morphological character traits in seed ornamentation. It has been a useful taxonomic character for identifying 24 species of Solanaceae [30]. Seed weight per fruit is the trait with the most phenotypic variation in *S. betaceum* [31], although it has more hair than other *Solanum* seeds from BTSNP. The seeds of *A. trifoliolata* (Rutaceae) are pale brown to dark brown colored, spheroid in shape, with a rough and stringy texture. The specific trait of this species is the tapered tip and base of seed. The seed coat of *A. trifoliolata* is hard and thus it needs breaking dormancy [32].

Table 2. Seed morphological qualitative characters of 12 plant species from BTSNP.

Species Name	Family	Seed qualitative characters			
		Color	**Texture**	**Shape**	**Specific trait**
Acronychia trifoliolata Zoll. & Moritzi	Rutaceae	Pale brown to dark brown	Rough and stringy	Spheroid	Tapered tip and base of seed
Amaracarpus sp.	Rubiaceae	Pale brown with dark brown to black	Rough, notched and semi-circle	Broad elliptic	The rounded oblong seeds, each with a flat face marked by a lengthwise groove, clear boundaries
Cayaponia laciniosa (L.) C. Jeffrey	Cucurbitaceae	Cream	Rough, have cuneiform pattern at the middle of seed shape	Cuneiform	Wedge-shaped with clear pattern on the seed surface
Eumachia montana (Blume) I.M. Turner	Rubiaceae	Grey	Rough and semi-circle	Ovoid broad elliptic	The rounded oblong seeds, each with a flat face marked by a lengthwise groove, no clear boundaries
Fragaea blumei G.Don	Gentianaceae	Brown	Rough (like cracks)	Fusiform to cuneiform	Small in size, shiny with fusiform
Phytolacca icosandra L.	Phytolaccaceae	Black	Shiny and smooth	Semi-deltoid to spheroid	Small seeds with very hard outer shells and black shiny
Pinanga coronata (Blume ex Mart.) Blume	Arecaceae	Black	Ribbed and stringy	Broad ovoid to elliptic	A woody or fibrous surface
Ricinus communis L.	Euphorbiaceae	Dark brown with cream to pale brown pattern	Smooth and shiny	Broad elliptic with blunt base	Oval seed shape with light to dark brown seed coat color, oily seed
Solanum betaceum Cav.	Solanaceae	Pale brown	Cream color hairs	Thin (plateriform) and ovoid	Cream color hairs on the seed surface (regular reticulate).
Solanum capsicoides All.	Solanaceae	Golden yellow	Rough with texture pattern	Tiny, spheroid to narrow square	Golden yellow seed with pattern at the surface
Solanum pseudocapsicum L.	Solanaceae	Cream to yellowish white	Rough	Thin (plateriform) and broad kidney	Cream to yellowish white seed with rough seed surface
Zapoteca tetragona (Willd.) H.M.Hern.	Leguminosae	Black	Smooth and shiny	Oblong to fusiform	Hard outer shells as all legume seeds

The combination of seed size and seed coat hardness of *Citrus garrawayi* (Rutaceae) is useful to estimate seed physiological and morphological maturity [33]. The seed coat hardness is also a main character seed of *Z. tetragona*, as well as the other legume seeds and *P. icosandra* from Phytolaccaceae. Most Fabaceae have impermeable seed coats and thus have physical or physiological dormancy [34, 35]. The seeds of *P. americana* and *P. acinosa* are smooth and shiny black, the seed testa is thick with reniform to orbicular in shape [36]. *F. blumei* seeds have specific traits, such as shiny, tiny and fusiform. Seeds of *P. coronata* are the same as other members of Arecaceae (palms), with woody or fibrous surface. The identification of palm seeds in the Amazon basin provides an interesting identification tool based on seed shape as part of seed morphometry. The morphometry of palm fruits and seeds, especially the fibrous seed surface, corresponds to a diversity of dispersion types in relation to survival adaptation [37]. The castor bean or *R. communis* seeds have great variation in seed coat color, meanwhile, its qualitative characters can differentiate various hybrids and their parental lines [38].

Seed morphological quantitative characters of 12 plant species from BTSNP are shown in Fig. 3.

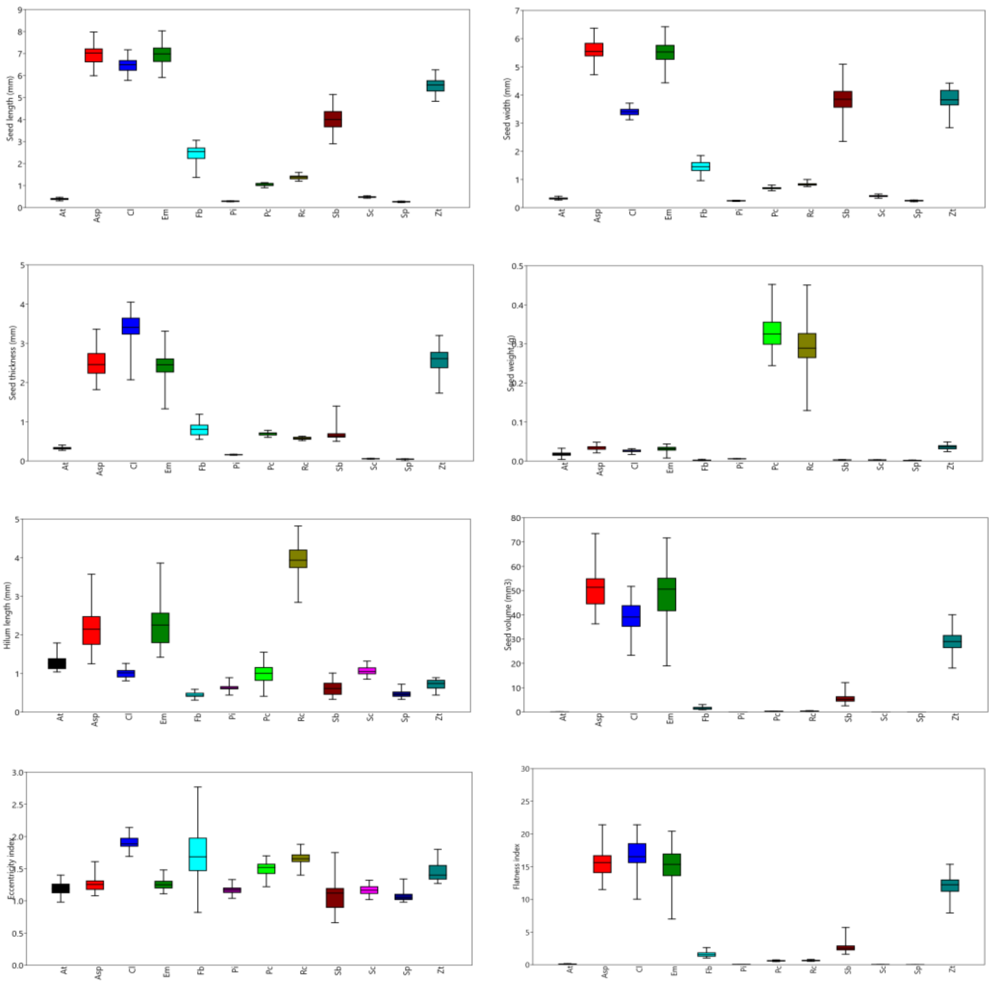

Fig. 3. Seed morphological quantitative characters of 12 plant species from BTSNP: At = *Acronychia trifoliolata*, Asp = *Amaracarpus* sp., Cl = *Cayaponia laciniosa*, Em = *Eumachia montana*, Fb = *Fragaea blumei*, Pc = *Pinanga coronata*, Pi = *Phytolacca icosandra*, Rc = *Ricinus communis*, Sb = *Solanum betaceum*, Sc = *S. capsicoides*, Sp = *S. pseudocapsicum* and Zt = *Zapoteca tetragona*

Amaracarpus sp. has the longest and the widest seed hence it also has the largest volume. The thickest seed belongs to *C. laciniosa* in which this character was correlated with EI and FI values. The seed thickness determines the seed shape and surface flatness. *P. coronata* has the heaviest seed and *R. communis* has the longest hilum. The seed size is significantly related to the mean body size of frugivores, whereas the size of frugivores becomes the strongest driver of the seed size variation [39]. It means that the morphological variation of seed shape determines the size of seed dispersal agent.

The quantitative characters give more contribution to grouping than qualitative characters, except hilum size and EI value. EI value is related to seed shape in which, in this case, it had no influence on the seed grouping of the species studied. It is presumably because shape variations were not too diverse. *Cervantes and Gomez* [40] stated that shape is the result of a plant growth process. In one individual plant, sometimes there are differences in the fruits or seeds shape caused by many factors. These factors include the position of seed formation in developing fruit, inflorescence or pollinator type, and fruit type. The seed shape is also closely related to the way it is spread and hence, determines its dispersal. Prediction of seed dispersal from 12 plant species in BTSNP shows that most of those seeds are dispersed by animals. This mechanism is related to the morphology of fruit. An edible fleshy fruit and thick fleshy seeds correspond to the zoochorous dispersal syndrome (*i.e.,* plant species whose seeds are dispersed by frugivorous animals). On the other hand, fruit or seeds which have waterproof coverings and fibrous husks will be dispersed by water (such as seeds of *P. coronata*).

In addition, the size of seeds also affects seed dispersal. *De Jager et al.* [41] stated that in lowland streams, the smaller seeds generally disperse at shorter distances than larger seeds. The seed dispersal strategy relates to its germination strategy, indicating that the seed shape indirectly affects the dispersal and germination type [41-43]. *Zhou et al.* [44] explained that seed morphological characteristics become one of the factors affecting the seed dispersal through seed dispersal trajectory, in addition to environmental factors.

PCA of the seed morphometry of 12 plant species from BTSNP

The PCA results show that there are two groups of 12 plant species from BTSNP influenced by the morphometric characters (Fig. 4). The first two principal components of the PCA have eigenvalues of 5.32 and 2.17, respectively, and contribute to cumulative 68.10% of the total variance (Table 3). Group I is the seeds influenced by weight, color, size of hilum, shape, texture, and EI value, including *A. trifoliolata, F. blumei, P. icosandra, P. coronata, R. communis, S. capsicoides,* and *S. pseudocapsicum*. Group II is the seeds influenced by length, width, thickness, volume, and FI value, including *Amaracarpus* sp., *C. laciniosa, E. montana, S. betaceum* and *Z. tetragona*. Seeds of *F. blumei* are highly influenced by color and surface characters, whereas length, width, thickness, volume and FI value characters strongly influence *Z. tetragona* seeds. According to PCA results (Fig. 5), the quantitative characters also give more contribution to grouping than qualitative characters. However, among the quantitative characters, it turns out that EI value and the hilum size do not contribute more compared to the other characters. EI value is related to seed shape, but hilum size is related to seed germination because hilum is a part of the seed that functions for radicle emergence in the imbibition process and controls relative humidity. As mentioned by *Hyde; Rodrigues-Junior et al.* [45, 46], hilum is a hygroscopically activated valve in the permeable epidermis of the testa which has an opening and closing motion. In this case, the quantitative characters like seed length, width, thickness, volume, and FI value can be used to distinguish 12 plant species at the species level, but the EI value and hilum size cannot. Previous study indicated that seed shape and the hilum character of *Oxytropis* species are useful to identify up to the species level [47].

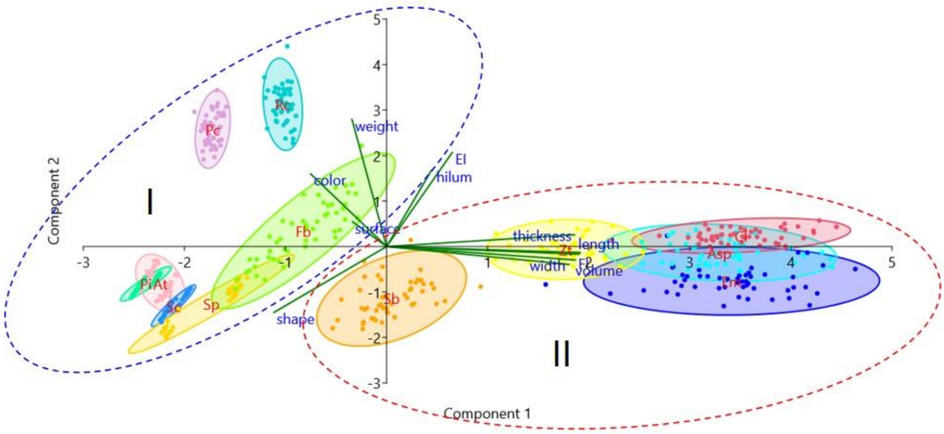

Fig. 4. PCA results from seeds morphometry of 12 plant species from BTSNP: At = *Acronychia trifoliolata*, Asp = *Amaracarpus* sp., Cl = *Cayaponia laciniosa*, Em = *Eumachia montana*, Fb = *Fragaea blumei*, Pc = *Pinanga coronata*, Pi = *Phytolacca icosandra*, Rc = *Ricinus communis*, Sb = *Solanum betaceum*, Sc = *S. capsicoides*, Sp = *S. pseudocapsicum* and Zt = *Zapoteca tetragona*.

Table 3. Eigenvalue and total variance of seeds morphometry of 12 plant species from BTSNP.

PC	Eigenvalue	% variance
1	5.32	48.38
2	2.17	19.72
3	1.21	11.03
4	0.84	7.64
5	0.69	6.26
6	0.54	4.94
7	0.16	1.44
8	0.058	0.52
9	0.009	0.08

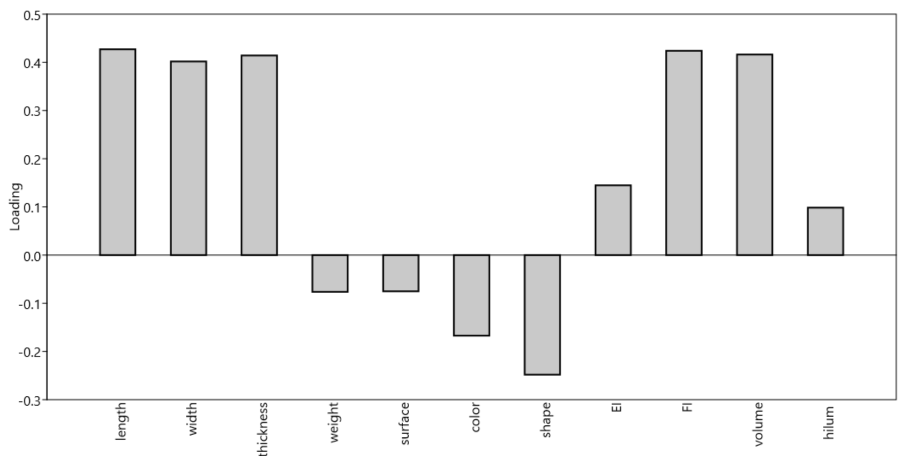

Fig. 5. Loading plot contribution of seed morphometry characters; EI = Eccentricity Index, FI = Flatness Index

Furthermore, the seed grouping patterns of 12 plant species in BTSNP according to PCA and cluster analysis are relatively the same, especially for *Amaracarpus* sp., *C. laciniosa*, *E. montana*, and *Z. tetragona*. Grouping using PCA can be determined based on quantitative characters, such as length, width, thickness, FI value, and seed volume, except hilum size and EI value. Grouping based on cluster analysis is more effective in distinguishing quantitative characters, especially seed length, width, thickness, and FI value. It shows that the variety of seed texture or surface is useful to describe large morphological diversity. As stated by [48], cluster analysis on seed morphometry of *Elaeagnus multiflora* can describe seeds morphological diversity. The FI value is commonly used to describe the shape morphology of seeds or particles, a value of 1 for spheres and value of more than 2 for spindly seeds [19, 49]. The seed volume also affects the seed grouping, as it plays an important role in seed morphology, helping to classify seeds into size categories. The seed processing such as drying, dressing, and scarification methods is significantly governed by seed volume. Smaller seeds generally experience less damage during seed processing compared to larger ones. The seed volume is related to the sphericity index which can be estimated based on the dimensions of a relatively small number of seeds [50].

Two-way clustering pattern of 12 plant species from BTSNP based on seed morphometry

Cluster analysis revealed that seeds of 12 species are divided into two groups based on 11 seed morphometry characters (Fig. 6). The two groups begin to separate at a distance of 8.0–12.8. Group I has more length, width, thickness, and FI values than Group II. Group I has a length range between 5-6mm, a width of 3-5mm, a thickness of 2-3mm, and FI value of 12-16. The seeds species in Group II such as *Amaracarpus* sp., *C. laciniosa*, *E. montana,* and *Z. tetragona* have smaller FI values, hence their seed surface or texture is rougher or more grooved than seeds species from Group I. It indicates a positive correlation between the FI value and the seed surface or texture. The greater the FI value, the smoother the seeds surface or texture.

Based on two-way clustering pattern (Fig. 6) and similarity index (Table 4), seed length, width, weight, volume, and EI value are quantitative characters that support the grouping based on the similarity. Meanwhile, the other quantitative characters, such as hilum size and EI value, have more variations, as well as qualitative characters. These results are similar to PCA results. Furthermore, these characters bring little impact on grouping. Seeds from Group I have medium seed weight (0.026-0.036g), larger seed volume (28.96-51.4mm^3), higher FI value (12.15-16.86), longer seed (5.552-6.982mm), and thicker seed (2.436-3.413 mm) than seeds from Group II. Seeds from Group II have varied seed weight (light seeds with range between 0.002-0.018g, heavy seeds such as *R. communis* (0.29g) and *P. coronata* (0.329g)), smaller seed volume (0.006-5.399mm^3), lower FI value (0.0011-2.636), shorter seed (0.477-4.009mm), and thinner seed (0.045-0.816mm) than seeds from Group I.

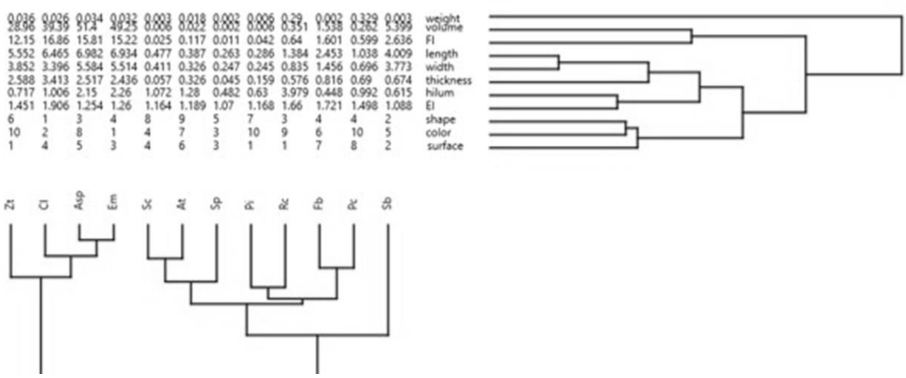

Fig. 6. Two-way clustering pattern of 12 plants species based on seed morphometry characters; At=*Acronychia trifoliolata,* Asp=*Amaracarpus* sp., Cl=*Cayaponia laciniosa,* Em=*Eumachia montana,* Fb=*Fragaea blumei,* Pc=*Pinanga coronata,* Pi=*Phytolacca icosandra,* Rc=*Ricinus communis,* Sb=*Solanum betaceum,* Sc=*S. capsicoides,* Sp=*S. pseudocapsicum* and Zt=*Zapoteca tetragona.*

Table 4. Similarity index of 12 plant species based on seed morphometry characters: At=*Acronychia trifoliolata*, Asp=*Amaracarpus* sp., Cl=*Cayaponia laciniosa*, Em=*Eumachia montana*, Fb=*Fragaea blumei*, Pc=*Pinanga coronata*, Pi=*Phytolacca icosandra,* Rc=*Ricinus communis,* Sb=*Solanum betaceum*, Sc=*S. capsicoides*, Sp=*S. pseudocapsicum* and Zt=*Zapoteca tetragona*.

Species	At	Asp	Cl	Em	Fb	Pi	Pc	Rc	Sb	Sc	Sp	Zt
At	1											
Asp	0.29	1										
Cl	0.20	0.85	1									
Em	0.20	0.93	0.87	1								
Fb	0.71	0.37	0.32	0.30	1							
Pi	0.76	0.24	0.13	0.15	0.56	1						
Pc	0.76	0.33	0.24	0.23	0.81	0.72	1					
Rc	0.61	0.31	0.21	0.22	0.64	0.72	0.75	1				
Sb	0.45	0.42	0.43	0.39	0.67	0.44	0.51	0.54	1			
Sc	0.85	0.24	0.21	0.20	0.63	0.73	0.64	0.54	0.46	1		
Sp	0.68	0.19	0.18	0.19	0.60	0.66	0.59	0.51	0.45	0.81	1	
Zt	0.35	0.77	0.78	0.75	0.42	0.42	0.41	0.40	0.53	0.30	0.26	1

Quantitative characters are free from subjectivity hence the value is more accurate. *Mandarim-de-Lacerda & del Sol* [51] mentioned that quantitative morphological characters contribute to low subjectivity and are reproducible. Meanwhile, qualitative characters such as seed color, shape and texture are not very influential. It is because qualitative characters have more diverse variations and involve high subjectivity, and consequently, they are less accurate as also assumed by *Gaad et al.* [52]. The large morphological variation indicates the existence of wide genetic diversity among species thus it is useful assist in the conservation of genetic resources as well as classification purposes [53].

The dispersal seed mechanism based on seed morphometry characters of 12 plant species from BTSNP

Characters of seed morphometry are related to seed dispersal. The seed dispersal agent is related to the seed general adaptation to the environment. There are several modes of seed dispersal which include animal (zoochory), wind (anemochory), water (hydrochory), and self-dispersal (such as explosive fruits and creeping diaspores). This mechanism is related to fruit and seed morphology [24]. The dispersal seed mechanism of 12 plant species from BTSNP is shown in Table 5. Most of the seeds of 12 plant species from BTSNP have fleshy fruits, hence they are allegedly dispersed by animals, such as birds, bats, and non-flying mammals (zoochory mechanism). Animals will disperse seeds based on morphological characters i.e., color, shape, texture, and scents of seeds and generally found in fleshy fruits [43, 55, 56]. Seeds of *R. communis* and *Z. tetragona* are dispersed by self-dispersal since they have explosive fruits. This is in line with *Martins and Haddad* [57] that seed dispersal of *R. communis* worldwide is primarily dispersed by autochory and secondary dispersed by ants (despite the relatively enormous seed size).

Morphometric analysis is needed in plant conservation efforts, especially in plant taxonomy, for example to determine species morphological variations and to identify species. It can also be used as a supporting character for certain taxa [66, 67]. In addition, it also plays a role in ecology studies, for example to determine morphological variations based on the ecological characteristics of their habitat. Morphometric analysis plays a significant role in understanding geohydrological characteristics (soil and water conservation), particularly in estimating infiltration rates and runoff [68]. Besides that, morphometric analysis including the size, color, and texture also related to seed ecology through seed dispersal.

Systematic studies on seed plants (Angiosperms) are not enough to use only one part of the plant. Fruit and seed characters are advantageous to determine plant species. As shown from the results of cluster analysis in this study, where species from the *Solanum* genus are in one group.

Table 5. The dispersal seed mechanism of 12 plant species from BTSNP.

No	Species	Seed dispersal mechanism	Reference
1	*Acronychia trifoliolata* Zoll. & Moritzi	Zoochory (birds; ornitochory)	[58]
2	*Amaracarpus* sp.	Zoochory (birds; ornitochory)	[59]
3	*Cayaponia laciniosa* (L.) C. Jeffrey	Zoochory (bats)	[60]
4	*Eumachia montana* (Blume) I.M. Turner	Zoochory	Prediction based on the morphology of fruit
5	*Fragaea blumei* G.Don	Zoochory (bats)	[61]
6	*Phytolacca icosandra* L.	Zoochory (birds, mammals)	[62]
7	*Pinanga coronata* (Blume ex Mart.) Blume	Zoochory (birds, bats, non-flying mammals)	[63]
8	*Ricinus communis* L.	Self-dispersal (explosive fruits)	[64]
9	*Solanum betaceum* Cav.	Zoochory (birds; ornitochory), can also dispersed by anemochory and hydrochory	[65]
10	*Solanum capsicoides* All.		
11	*Solanum pseudocapsicum* L.		
12	*Zapoteca tetragona* (Willd.) H.M.Hern.	Self-dispersal (explosive fruits)	Prediction based on the morphology of fruit

Likewise, seeds of *Amaracarpus* sp. are in the same group with seeds of *E. montana*: both come from Rubiaceae. *De Melo et al.* [69] stated that morphological characterization of *Acacia farnesiana* from Fabaceae always includes the fruit and seed morphological characters. In addition, study of seed morphometric analysis correlates to their germination. Asymbiotic seed germination of several species of micro-orchids can be determined based on their morphology and morphometric studies [70]. Moreover, seeds morphometry through their morphological characters is helpful for plant phylogenetic studies [71].

Conclusions

Quantitative morphological characters such as length, width, thickness, FI value and volume of seeds were the most influential morphometric characters in identifying the seeds of 12 plant species in BTSNP. Qualitative morphological characters such as seed shape, color and texture brought no effect due to their small variations thus affecting subjectivity. The seeds of 12 plant species in BTSNP were mostly dispersed by animal or zoochory mechanism, for their fleshy fruit.

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