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An Image-based Approach of Apex Type Descriptor State Establishment using Elliptic Fourier Analysis

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ABSTRACT

An objective method to establish apex and base type descriptor states is proposed using elliptic Fourier descriptors derived from appropriately segmented images. Using pili (*Canarium ovatum* Engl.) kernel-in-shell apex as a model, 51 pili accessions represented by 10 kernel-in-shell images per accession were acquired using a calibrated VideometerLab3 setup. An appropriate segmentation scheme was applied by developing an algorithm that would segment blobs that cover only the apical region (upper 25%) of the closed contours using OpenCV implemented in Python 3.7. From the segmented blobs, elliptic Fourier descriptors (EFDs) were derived. Subsequently, the EFDs were analyzed using principal component analysis and cluster analysis. Two effective principal components were able to explain 94.18% of the variation which were visualized to show differences involving length to width ratio, apex angle and left-to-right leaning orientation of the segmented images. Although a single apex shape was observed, mean EFDs of three clusters were able to represent three apex type descriptor states-narrowly acute, acute and widely acute. This indicated that elliptic Fourier analysis can characterize variations in the apical regions, particularly apex shape and angle, given the proper segmentation protocol.

Key words: Apex, Base, Characterization, Descriptor states, Image-based phenotyping.

Descriptor lists, which have been developed to characterize and evaluate plant genetic resources, are composed of descriptors (traits) and corresponding descriptor states (trait states) (Bioversity International, 2007). The trait states are often a representation of the overall observed phenotypic variation of the taxon and are usually established using subjective means. Because of this, objective means of trait state representation state have been proposed, particularly in color (Gentallan *et al*., 2019a) and overall shape (Gentallan *et al*., 2019b), using image-based platforms. Despite this, there are still more characteristics that need to be methodically represented, *i.e*. margin type, surface texture and apex shape. On the other hand, elliptic Fourier analysis have been frequently used to numerically characterize biological shape variations in many plant species (Adebowale *et al*., 2012; Iwata *et al*., 2015; Chitwood and Otoni, 2017). This method, however, has not been used to specifically target the shape characterization of apices which is morphologically distinct from the overall shape of an organ.

Apex traits can taxonomically characterize plants and have been included in various descriptor lists to delineate interspecific differences of crops (IPGRI, 1995; Prohens *et al*., 2004; Kehlenbeck *et al*., 2015). It is hypothesized that apex types, based on angles and shapes, can be characterized using elliptic Fourier descriptors given the appropriate segmentation method. Thus, the study aimed to systematically establish and visually represent apex shape descriptor states using pili (*Canarium ovatum* Engl.) kernel-in-shell apex as a model.

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Fifty-one (51) accessions of pili (*Canarium ovatum* Engl.) from the Institute of Crop Science and National Plant Genetic Resources Laboratory (NPGRL), Institute of Plant Breeding, College of Agriculture and Food Science, University of the Philippines Los Baños, were used. Ten kernel-in-shell images per accession were then acquired using a calibrated VideometerLab 3 setup at a resolution of ~45 µm/pixel (Videometer A/S Hørsholm, Denmark). The segmentation scheme of apical portions was based on the definition of Ash (1999) and Ellis (2009) where it is defined as the characteristic of the upper 25% of a closed contour and is easily estimated by sectioning the covered region of the upper 25% of the total length. The background-removed and reoriented blobs were segmented using OpenCV library implemented in Python 3.7 to get a closed contour of described standard apical regions. This was done by implementing a segmentation algorithm that would crop the region of the blob that is covered by the upper 25% of the total length. Then, the procedure for deriving standardized elliptic Fourier descriptors (EFDs) and its subsequent descriptor state establishment was derived from Gentallan *et al*. (2019b) using Shape version 1.3 software (Iwata and Ukai, 2002) using 20 harmonics. The derived EFDs were subjected to principal component analysis (PCA) to summarize significant and uncorrelated trait variations observed, cluster analysis to group similar images that would represent a descriptor state and visualization to project representative outlines of each cluster using Shape version 1.3, SHAPE on R (Iwata and Ukai, 2002) and XLSTAT 2016 (Addinsoft, Inc., Brooklyn, NY, USA). The final descriptor states were established based on the re-projected visualizations of the mean EFDs per cluster.

Two principal components (PCs) were able to explain 94.18% of the total trait variation and had an eigenvalue greater than one divided by the total number of PCs. This indicates that the two PCs can effectively describe the trait variations observed in the given set of images. Through analysis of the trait variations per component, it was observed that the first principal component was able explain 78.91% of total trait variations which is explained by the varying length to width ratio of the apical region and, consequently, the apex angle (Fig 1). The second principal component describes the 15.28% of the total variation describes the left to right leaning orientation of the apices (Fig 1).

Taking this into consideration, using the factor scores from the PCA, cluster analysis using unweighted pair group method with arithmetic means (UPGMA) and sequential, agglomerative, hierarchical and nested clustering parameters (SAHN) revealed in the evolution of variances across increasing number of classes that variance within clusters is <20% and any additional cluster will entail <10% decrease in the variance within clusters if the dendrogram is cut to produce three classes/clusters. Hence, three clusters were used to represent the kernel-in-shell apex shape descriptor states of pili (Fig 2).

The visualized average EFDs per cluster represented three trait states that are all under the "straight" state of apex shape showing no significant curvatures of the designated apical region (Ash, 1999; Ellis, 2009); however, it can be observed that the apex angle across the three

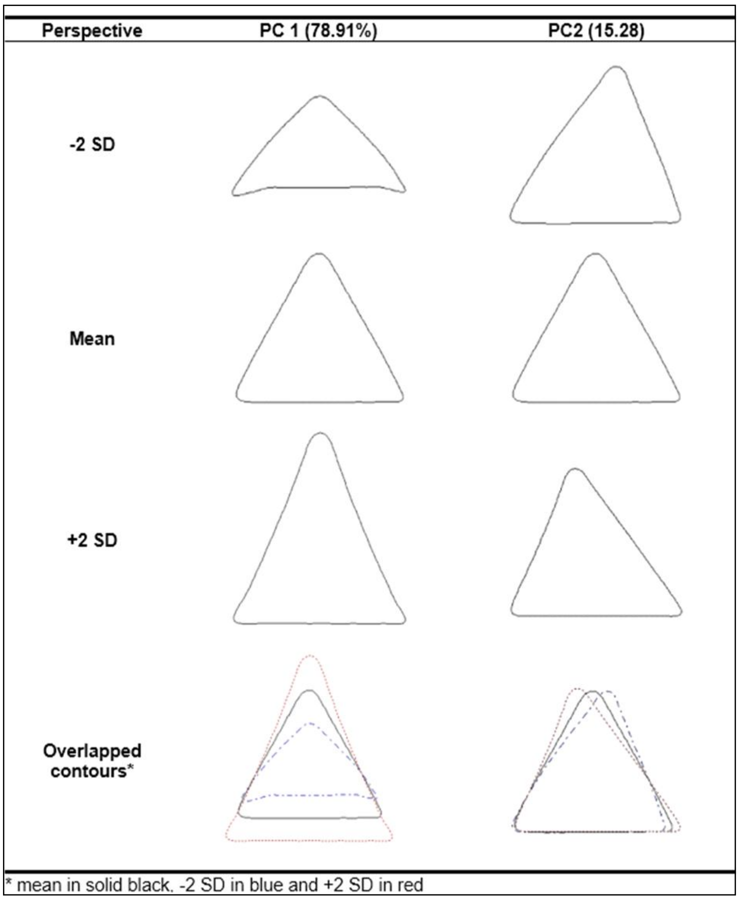

Fig 1: Apex shape variations explained by the first two effective principal components; SD indicates standard deviation; *mean in solid black, -2 SD in blue, +2 SD in red.

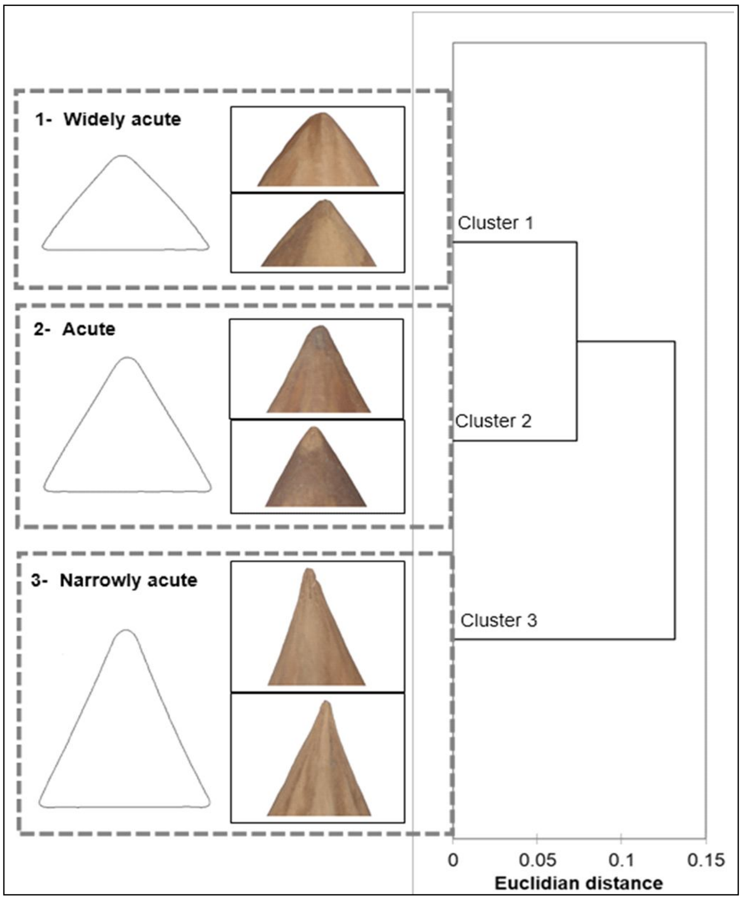

Fig 2: Apex descriptor states represented by mean shape outlines of the three distinct clusters.

clusters were varying from 45° to 90° indicating that it is within the "acute" spectrum of apex angle (Simpson, 2010; Simpson, 2019). As prescribed by Bioversity International (2007), to accommodate the wide range of users of the descriptor lists, the identified three apex types are simplified further to narrowly acute (45° to 60°), acute (>60° to 75°) and widely acute (>75° to 90°) to represent the trait variations in pili kernerl-in-shell apices (Fig 2). These indicated that EFDs were able to objectively characterize the variations in the apical regions, both in shape and angle, given the appropriate segmentation rule. The bottleneck of the method lies in the subjectivity of identifying the reasonable number of clusters/classes that can thoroughly represent the trait variations without overcomplicating the method of characterizing plants using descriptor lists.

Although pili kernel-in-shell apex type was used as a model, objective schemes in establish apex type and base type descriptor states can be applied to characterize two-dimensional closed-contour components of other plant organs of various plant species.

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CONCLUSION

Image blobs, that cover only the apical region (upper 25%) of the closed contours, were segmented and elliptic Fourier descriptors (EFDs) were derived. From the resulting EFDs, three apex type descriptor states- narrowly acute, acute and widely acute, were elucidated through PCA and cluster analysis; hence, elliptic Fourier analysis can characterize two-dimensional shape differences of various parts of plant organs, given a suitable segmentation protocol.

Conflict of interest: None

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