BIODIVERSITAS
Volume 20, Number 10, October 2019
Pages: 2809-2814

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d201005

Short Communication: Morphology and taxonomic relationships of shallot (*Allium cepa* L. group aggregatum) cultivars from Indonesia

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Manuscript received: 19 July 2019. Revision accepted: 3 September 2019.

Abstract. *Fitriana N, Susandarini R. 2019. Short Communication: Morphology and taxonomic relationships of shallot (*Allium cepa *L. group aggregatum) cultivars from Indonesia. Biodiversitas 20: 2809-2814.* Shallot is an important vegetable crop commodity in Indonesia, and its ranks third in terms of cultivation area after chili (*Capsicum annuum* L.) and cabbage (*Brassica oleracea* L.). There are a number of superior cultivars of this species that have been studied in terms of their morpho-agronomic traits, but their morphological variability and its implication to taxonomic relationships have not been studied in depth. This study aimed at documenting morphological variability and taxonomic relationships of 12 superior shallot cultivars using numerical taxonomic approaches. Sixteen morphological characters from leaves and bulbs were used in cluster analysis and principal component analysis. The results revealed that twelve shallot cultivars from Indonesia showed significant variability in leaf and bulb morphology, particularly in quantitative characteristics as indicated from ANOVA. The grouping of cultivars and their taxonomic relationships generated from cluster analysis and principal component analysis revealed the role of bulb morphology as determining characteristics in the grouping of cultivars. This study suggested the importance of bulb morphology in the characterization of shallot cultivars.

Keywords: Characterization, morphology, multivariate analysis, shallot

INTRODUCTION

Allium cepa L. is a member of the family Alliaceae J.G. Agardh, which has been cultivated since ancient time as vegetable. Three horticultural groups were recognized within this species, namely the Common Onion group, Aggregatum group, and Ever-ready Onion group (Fritsch and Friesen 2002). The Aggregatum group, known as shallot, which is characterized by aggregated cluster of lateral bulbs of smaller size than common onion group (Shigyo and Kik 2008). The edible part of shallot is its bulb which composed of several layers of inner fleshy and enlarged leaf bases, and covered by the outer dry membranaceous scaly leaves (Pareek et al. 2018; Teshika et al. 2018). The tunicated bulb is structurally a modified underground stem and leaves, and its shape varies from oval, globe, elliptic, to spindle (Teshika et al.2018).

Besides being used as vegetables or spices, shallot has been known for a long time as a medicinal plant. The health benefit of shallot is believed due to organo-sulfur compounds and quercetin, and also a number of mineral compounds including calcium, magnesium, sodium, potassium, selenium, and phosphorus (Kumar et al. 2010). Quercetin, a flavonoid compound is found in shallot bulb, is the main element which gives various therapeutic properties, including anti-allergenic, anti-inflammatory, cardio-protective, vasodilatory, anti-carcinogenic, antioxidant, antibacterial and antifungal (Upadhyay 2016; Shafiq et al. 2017). The organo-sulfur compounds in shallot bulbs are causing its distinctive odor and taste (Friesen et al. 2006), and is responsible for bulb pungency (Sekara et al. 2017).

Allium cepa L. is now cultivated worldwide and become important horticultural commodity in Africa, Europe, Asia, and America (Shrestha 2007; Shigyo and Kik 2008). Among the three horticultural groups, shallot is more important in lowlands areas of tropical countries compared to common onion, and now it is mainly cultivated in Southeast Asia and Africa (Shigyo and Kik 2008). In Indonesia shallot is produced in 24 of 34 provinces, with major production centers include North Sumatra, West Sumatra, West Java, Central Java, East Java, Bali, West Nusa Tenggara, and South Sulawesi. Java hosts the main production areas for shallot which contributes 75% to the total shallot harvest in Indonesia, with Central Java and West Java hold the highest productivity (Siagian 2015). Based on this fact, therefore, this study was focused on superior shallots cultivars developed by the Indonesian Research Institute for Vegetables Crops and local cultivars collected from farmers in Java.

Diversity studies on shallot cultivars from Indonesia were mainly on their genetic analysis using molecular markers, such as phylogenetic relationships of *Allium cepa* var. *ascalonicum* and *Allium* x *wakegi* based *on* RAPD and RFLP technique have been reported by Arifin et al. (2000). Genetic diversity analysis of shallot based on *R gene*-derived markers conducted by Herlina et al. (2019) suggested that shallot in Indonesia have poor levels of genetic diversity. Meanwhile, morphological variation of shallot cultivars from Indonesia based on 11 characters and their genetic variation based on RAPD analysis was reported by Laila et al. (2013).

The objectives of this study were to document the morphological variability and taxonomic relationship of 12 shallot cultivars from Java Island, the major shallot production area in Indonesia. Information on morphological variability and taxonomic relationship of cultivated plants is important for the inventory of species diversity, germplasm exploration, conservation, and in providing basic data for breeding program.

MATERIALS AND METHODS

Materials

Twelve shallot cultivars used in this study were collected from the Indonesian Research Institute for Vegetables Crops (IRIVC) and local farmers (Table 1). Vegetative bulbs were used as planting materials, from which morphological characters were examined on fully developed plants.

Methods

The vegetative bulbs were planted in 20 x 25 cm polybags filled with 5 kg of soil mixed with 60 g of compost, and 2 g of SP-36 fertilizer per polybag. One bulb was planted in each polybag, and five replicates were prepared for each cultivar. The humidity of the planting media was set in the range of 50-70% by daily watering. After 2 and 4 weeks of planting, the fertilizers were added, consisting of 1.5 g urea, 6 g ZA, and 3 g KCl per polybag. The plants were maintained for 75 to 100 days until the produced underground bulbs were ready for harvest.

Observation of morphological characters was done on leaves and bulbs, consisted of 14 characters from descriptors for *Allium* spp. (IPGRI 2001) and Protocol for DUS testing from CPVO (2009), with 2 additional characters created by the authors during data collection (Table 2).

Table 1. Shallot cultivars used in this study

Cultivar	Origin
Bauji	local cultivar from Nganjuk, East Java (collected from local farmer)
Bima	local cultivar from Brebes, Central Java (obtained from IRIVC)
Maja Cipanas	local cultivar from Cipanas, West Java (obtained from IRIVC)
Tiron	local cultivar from Bantul, Yogyakarta (collected from local farmer)
Katumi	hybrid of cv. Singkil Gajah and Thailand shallot
Kramat-1	hybrid of cv. Maja Cipanas and Gunung Batu onion
Kramat-2	hybrid of cv. Maja Cipanas and Gunung Batu onion
Mentes	hybrid of cv. B3117 and B3155
Pancasona	hybrid of cv. B2275 and B4127
Pikatan	hybrid of cv. B2558 and B3155
Sembrani	hybrid of Thailand shallot and common onion
Trisula	hybrid of cv. B228 and B4127

Table 2. List of morphological characters

Character	Character states
Foliage color	Light green; green
Foliage growth	Erect; spreading
Foliage cranking	Weak; medium; strong
Leaf length	Cm
Leaf width	Cm
Leaf length/width ratio	Ratio
Number of leaves per pseudostem	Count
Bulb shape	Broad oval; globe; ovate; spindle
Uniformity of bulb shape	Uniform; variable
Bulb skin color	Yellow; yellow and light brown; light brown; brown; dark brown; deep violet
Bulb skin thickness	Thin; medium; thick
Bulb flesh color	White; violet/white
Average number of bulbs per cluster	Few; medium; many
Bulb diameter	cm
Bulb hearting	Single; 2-3
Internal bulb layering *	3 layers-regular; 3 layers-irregular; 4 layers-regular; 4 layers-irregular; 5 layers-regular
Fresh bulb aroma *	Weak; medium; strong

Note: * indicates additional characters not listed in Descriptors for *Allium* spp. (IPGRI 2001) and Protocol of CPVO-OCVV (2009)

Data analysis

The morphological data were subjected for cluster analysis and principal component analysis using MVSP software version 3.1 (Kovach 2007). The dendrogram from cluster analysis was generated based on Euclidean distance and UPGMA clustering method. A one-way ANOVA was done for quantitative data using SPSS version 21.

RESULTS AND DISCUSSION

Results

Results of morphological observations showed variations on leaves and bulb characters. The most noticeable variations among 12 shallot cultivars were in their bulbs, especially the bulb shape and bulb skin color (Figure 1). Bulb shape varied from broadly oval, globe, ovate, and spindle. Bulb skin color showed higher variation, ranging from yellow, yellow to light brown, light brown, brown, dark brown and deep violet. Three cultivars were easily recognized by their yellow bulb skin color, namely the cultivars Sembrani, Tiron, and Bauji, whereas the rest eight cultivars showed gradation of bulb skin color from light brown and deep brown. One cultivar had a distinctive bulb skin color was Trisula with deep purple color.

Significant variations were found on quantitative characters (Table 3) as shown in the results of one-way ANOVA (Table 4). There was a significant difference among cultivars on five quantitative characters used in this study, as showed by the $p < 0.05$.

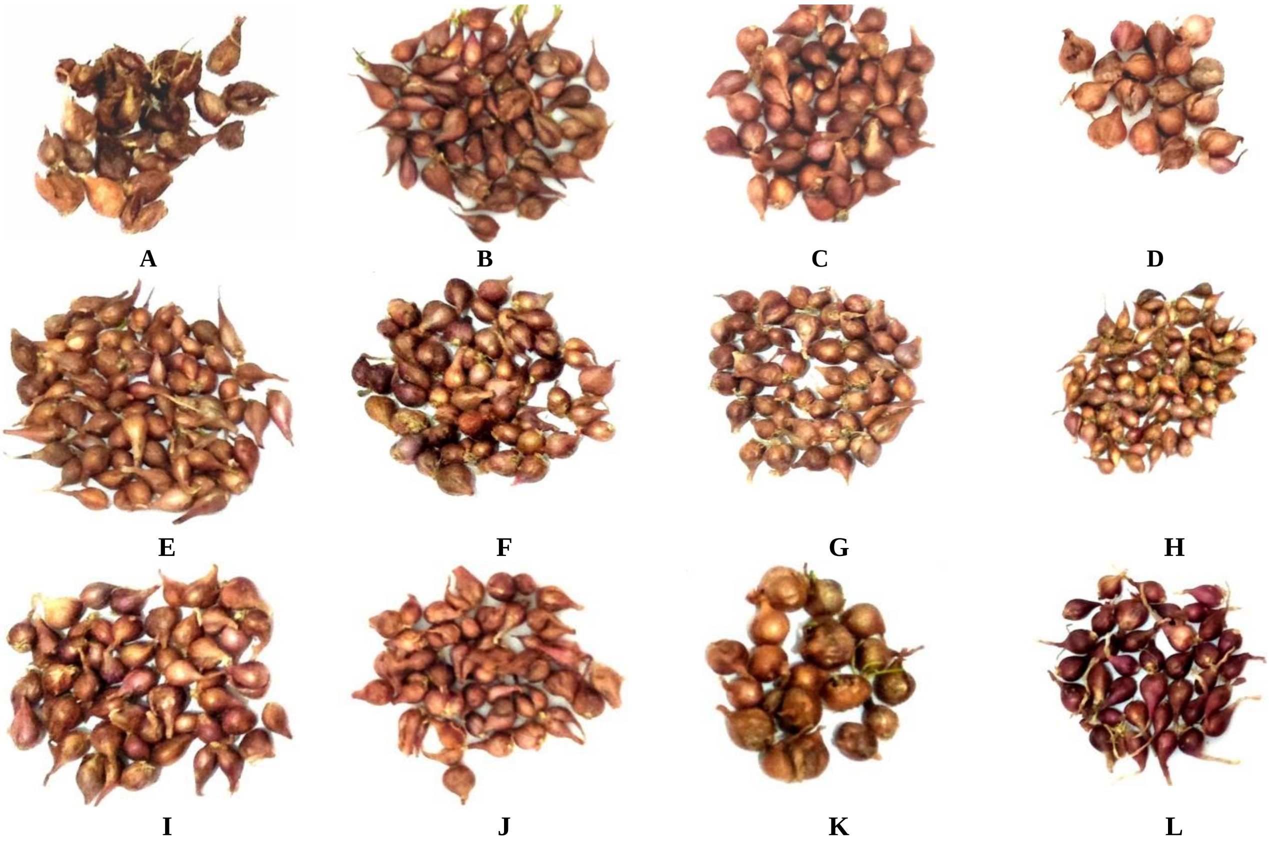

Figure 1. Variation on bulb shape and bulb skin color on 12 shallot cultivars. Cultivar names: A. Bauji, B. Bima, C. Maja Cipanas, D. Tiron, E. Katumi, F. Kramat-1, G. Kramat-2, H. Mentes, I. Pancasona, J. Pikatan, K. Sembrani, L. Trisula

Table 3. Mean and standard deviation of quantitative characters

Character	N	Mean	Std. deviation
Leaf length	12	37.275	3.734
Leaf width	12	0.738	0.184
Number of leaves per pseudostem	12	13.417	2.712
Average number of bulbs per cluster	12	9.917	3.088
Bulb diameter	12	1.404	0.309

Table 4. Results of ANOVA on quantitative characters

	Sum of squares	df	Mean square	F	Sig.
Between groups	10593.311	4	2648.328	427.590	0.000
Within groups	340.649	55	6.194		
Total	10933.960	59			

Results of cluster analysis on 12 shallot cultivars based on 16 morphological characteristics as shown in the UPGMA dendrogram (Figure 2) represented taxonomic relationships among cultivars. The grouping pattern on the dendrogram reflected similarities in morphology, and was mainly determined by bulb characters as indicated in the eigenvalues generated from principal component analysis (Table 5). The dendrogram displayed two clusters; each consisted of six shallot cultivars. Cluster I comprised of cultivars Pancasona, Maja Cipanas, Mentes, Katumi, Trisula, and Bima. Cluster II consisted of cultivars Bauji, Tiron, Kramat-1, Kamat-2, Pikatan, and Sembrani. The main differentiating characters of these two clusters were bulb skin color, bulb skin thickness, internal bulb layering, and bub shape. These four characters were marked by high loadings in the first axis of principal component analysis.

Cluster I and cluster II could be differentiated using these bulb characters. Members of cluster I were characterized by brown or dark brown bulb skin, except for Trisula with distinctive deep purple bulb skin, thick bulb skin, and their bulb shape was ovate or spindle. Meanwhile, shallot cultivars within cluster II were recognized from their bulbs with yellow or light brown skin color, thin or medium bulb skin, broadly oval bulb shape, except for Sembrani which has distinctive globe shape on its bulbs. It is obvious that the grouping of cultivars into one cluster was mainly determined by the similarity of bulb characteristics. Results of principal component analysis showed that bulb characters had significant contribution in the grouping of cultivars.

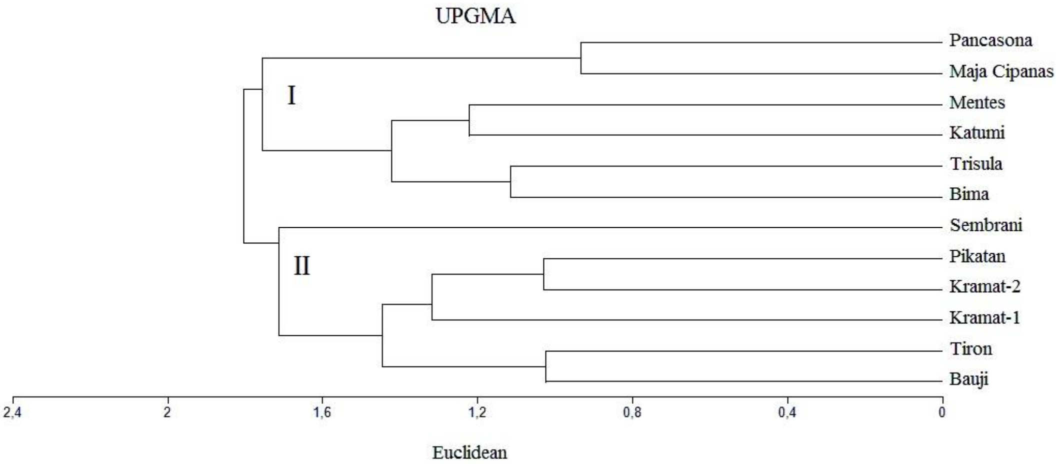

Figure 2. Dendrogram representing taxonomic relationships of 12 shallot cultivars based on morphological characters

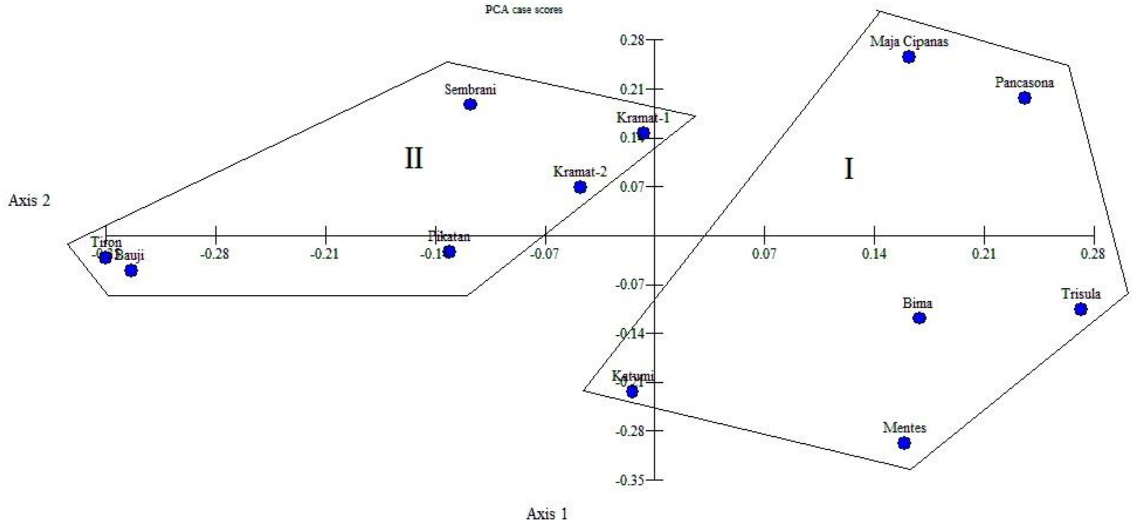

Figure 3. PCA plot of 12 shallot cultivars based on morphological characters

Table 5. Character loadings and the eigenvalues generated from principal component analysis

Character	PC1	PC2
Foliage color	0.067	0.035
Foliage growth	0.037	-0.049
Foliage cranking	-0.031	0.070
Leaf length	-0.107	**0.326**
Leaf width	0.096	**0.342**
Leaf length/width ratio	-0.145	**-0.317**
Number of leaves per pseudostem	-0.031	0.160
Bulb shape	0.264	**-0.548**
Uniformity of bulb shape	0.066	0.076
Bulb skin color	**0.728**	-0.146
Bulb skin thickness	**0.378**	0.011
Bulb flesh color	0.126	-0.006
Average number of bulbs per cluster	0.083	0.244
Bulb diameter	-0.012	0.219
Bulb hearting	0.023	0.032
Internal bulb layering	**0.355**	**0.432**
Fresh bulb aroma	0.235	0.141

Results of principal component analysis were presented as character loadings and eigenvalues (Table 5) and the PCA plot showing the grouping of cultivars (Figure 3). These results showed that the four aforementioned bulb characters had high loadings as indicated by a value of higher than 0.3 at the first principal component (PC1). These four characters were bulb skin color, bulb skin thickness, internal bulb layering, and bulb shape. Meanwhile, among the six-leaf characters observed, two of them showed high loading values in the second principal component (PC2), namely leaf width and leaf length.

Discussion

Observations on the morphological data in this study were carried out on plant individuals grown under the same conditions, so that the resulting variations reflected the true characteristics of each cultivar, and did not affect by environmental influences. The requirement to minimize the effect of environmental factors in morphological characterization of plant varieties has been underlined by Ahmed et al. (2013).

Variations on leaves qualitative characters, namely leaf color, foliage growth and foliage cranking were considered as criteria to differentiate *A. cepa* varieties (Ahmed et al. 2013). Variations on these three foliage characters were also reported in *Allium* species from Iran (Aryakia et al. 2016). Meanwhile, variations on number of leaves were reported by Laila et al. (2013) as one of morphological characters differentiating 16 shallot cultivars from Indonesia. Variations on leaf quantitative characteristics, including leaf length, leaf width, and number of leaves per individual plant observed in the study were in line with those reported by Khosa et al. (2014) in the study of morphological variations on *Allium* spp.

Another qualitative character of interest is bulb flesh color, in which the 12 shallot cultivars showed a variation from white to purple-white. In this regard, Schwinn et al. (2016) marked the role of bulb color as important trait in *A. cepa* related to consumer preference and its association with health benefit from various types of flavonoid compounds reflected in bulb color differences. There is a tendency that shallot with red bulbs has higher antioxidant (Singh et al. 2018). Furthermore, Khandagale and Gawande (2019) underlined the importance of bulb color as quality character in *A. cepa* breeding program and a criterion for varieties classification.

An interesting variation to be mentioned here is fresh bulb aroma or pungency, since this character determines the consumer preferences in choosing particular cultivar to be used as spices or condiment. The stronger pungency level indicated the higher flavonoid and isoalliin content in shallot bulbs (Ariyanti et al. 2018). Regarding the bulb pungency, Mallor et al. (2011) noted the role of pungency as an important quality attribute related to processing and storage of *A. cepa* bulbs.

Results of this study were in line with previous study on the characterization of *A. cepa* from Bangladesh using multivariate analysis (Rashid et al. 2012). The application of principal component analysis in exploring morphological variability and relationships of *Allium* spp. has also been reported by Khosa et al. (2014) who identify major or affecting variables on the grouping of samples based on evaluation of eigenvalues. Given that the plant materials used in this study were grown in the same conditions, the differences in morphological characters of bulbs and leaves were not influenced by environmental factors, instead, they reflected differences in genotype. Therefore, the grouping of cultivars resulted from cluster analysis based on morphological characters in this study seemed to indicate genotypic relationship.

The essential nature of assessment on morphological variation and taxonomic relationships using qualitative and quantitative characters for crop improvement through selection and breeding program has been noted by Arya et al. (2017). The application of cluster analysis in the study of morphological diversity in relation to selection strategy and breeding program has been pointed out by Mallor et al. (2011). In this case, the application of cluster analysis is in helping selection of materials for breeding program of *A. cepa* based on evaluation of particular traits such as bulb size and pungency.

This study emphasizes the importance of documenting morphological variability and assessment of taxonomic relationship of economically important plant species such as shallot. Comprehensive characterization provides strong basis conservation of germplasm and crop improvement through selection of superior varieties. Taxonomic relationships of shallot cultivars generated from cluster analysis in this study can be used as a basis in determining potential cultivars with combination of desirable characters for crossing experiments in obtaining superior shallot cultivars.

ACKNOWLEDGEMENTS

The authors acknowledge financial support for this research provided by Universitas Gadjah Mada, Yogyakarta, Indonesia under the scheme of Thesis Recognition Program 2019 granted to second author, with contract No. RTA No.3022/UNI/DITLIT/DIT-LIT/LT/2019.

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