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Heterophylly in *Murraya exotica* L. (Rutaceae)

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Abstract: Heterophylly, the existence of different leaf types and leaflet shapes on the same plant was observed for the first time in *Murraya exotica* L. populations from different locations in Java, Indonesia. In each population, three types of compound leaves (paripinnate, imparipinnate and intermediate) and three types of leaflet shape (oblong, rounded and obcordate) were observed. This heterophyllous condition was found on both juvenile and adult plants. The variation in leaf type and leaflet shape may be due to the environmental conditions prevailing at the time of leaf production directing leaf development or due to developmental noise caused by random interactions between genes and the environment.

Keywords: Heterophylly, Compound Leaves, Leaflet Shape, *Murraya Exotica*

Introduction

The genus *Murraya* [Rutaceae: Aurantioideae: Aurantieae] extends from India, through Sri Lanka, Southeast Asia, Taiwan, the Philippines, Borneo, Indonesia Indo-China, Thailand, New Guinea, New Caledonia and northern Australia (Swingle and Reece, 1967; Parrotta, 2001). Within this genus is the mock orange or orange jasmine, known as kemuning in Indonesia, which is commonly grown as an ornamental or hedge due to its glossy foliage and clusters of fragrant flowers. In addition, its leaves, bark and root bark have various medicinal uses including treatments for diarrhoea, dysentery, dropsy, joint pain and stomach ache (Parrotta, 2001). The mock orange is a host of *Diaphorina citri* Kuwayama [Hemiptera: Sternorrhyncha: Liviidae], the vector of huanglongbing (citrus vein-phloem degeneration) and has variously been reported as a host (Li and Ke, 2002; Lopes, 2006), possible host (Tirtawidjaja, 1981; Aubert, 1987), or non-host (Miyakawa, 1980; Koizumi *et al*., 1996; Dai *et al*., 2005) of the bacteria ('*Candidatus* Liberibacter spp.': Alpha Proteaceae) that cause this disease.

Despite the pharmacological importance of these plants to humans and their role in huanglongbing, the taxonomy of the mock orange is uncertain, with two taxa, *Murraya exotica* L. and *Murraya paniculata* (L.) Jack, being recognised by various authorities. This uncertainty began when the mock orange was first described. In 1767, material collected by Rumphius was described as being *Chalcas paniculata* by Linnaeus and in 1771, Linnaeus described material collected by König as *M. exotica,* clearly considering that the two sets of material belonged to different genera (Tanaka, 1929). Since this time, Stone (1985) and Howard (1988) have considered *M. exotica* and *M. paniculata* to be distinct species. Huang (1959) considered *M. paniculata* to be a variety or subspecies of *M. exotica*. However, Huang (1997) regarded them as distinct taxa. Tanaka (1929) and Swingle and Reece (1967) considered *M. exotica* to be a synonym of *M. paniculata*, whilst Mabberley (1998) suggested that *M. exotica* be best treated as a cultivar of *M. paniculata*.

Among the morphological characters used in the classification of *Murraya* is leaf shape with leaves typically being imparipinnate compound with 5 to 7 leaflets. However, observations in the field have shown the occurrence of heterophylly in *Murraya* (Sculthrope, 1967) with variation occurring in leaflet shape and compound leaf type. The objective of this study was to detail the morphological variation associated with heterophylly to aid the correct identification of forms of *Murraya*.

Materials and Methods

The materials observed were adult plants and seedlings of *M. exotica*. A total of 500 three-year-old

adult plants [300 plants at Bogor Botanical Gardens (BBG), 100 plants at the Faculty of Agriculture, Universitas Gadjah Mada (UGM), Yogyakarta and 100 plants at Purwodadi Botanical Gardens (PBG)]. In addition, 500 one-year-old seedlings planted at UGM, BBG and PBG were examined for the type of compound leaf and shape of the leaflets (conducted from October, 2004 to August, 2006). The seeds from the three-year-old plants were sourced from BBG and the one-year-old plants were propagated from seed from the three-year-old plants. Five randomly-selected individuals were selected from each of these sets of plants and assessed to determine: (i) The position of paripinnate and intermediate compound leaves and (ii) the number and the position of obcordate leaflets on the main stem (in one-year-old plants) or the main stem and branches (in three-year-old plants). Both immature, recently formed leaves that were still bright green and mature leaves that had turned dark green were assessed separately. From December, 2006 to December, 2008, plants grown at PBG, UGM and BBG were reassessed; at this time the plants were five-years-old. In addition, five-year-old plants at Purworejo were also assessed; the seed for these plants came from Florida, Brazil and China. Data were analysed by ANOVA using Statistica (Version 7, StatSoft, Inc.). Data were first tested for normality and homogeneity of variances using Levine's test. Data sets that were heteroscedastic were subjected to square root transformations before analysis.

Results

Type of Compound Leaves

Three types of compound leaves were found in *M. exotica*: Imparipinnate, paripinnate and intermediate. However, most leaves were imparipinnate. In the imparipinnate and paripinnate leaves, there were two types of position of the leaflets, alternate and opposite (Fig. 1).

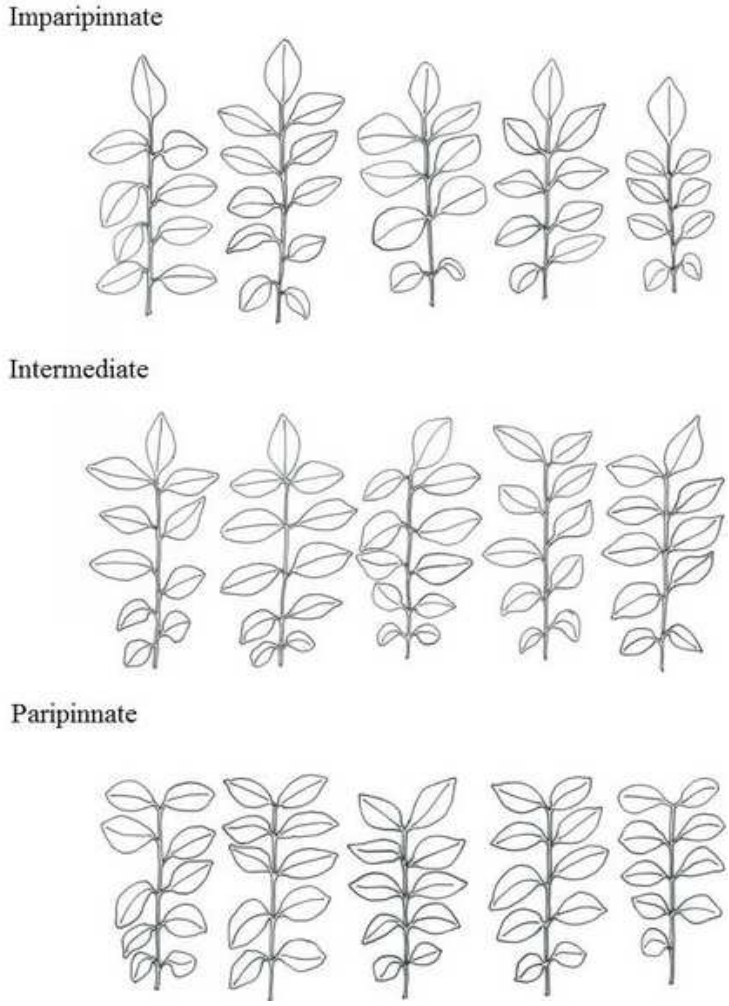

Fig. 1. Structure of the compound leaves of *Murraya exotica*

There were no differences in the number of paripinnate or intermediate leaves on the one-year-old plants at the three sites, nor between the young and mature leaves (data not shown). Among the three-year-old plants grown at BBG, PBG and UGM, there were no significant differences among sites in terms of the number of paripinnate or intermediate leaves, so the data from the different sites were combined. There was a trend for the stem and older branches to have more immature leaves that were paripinnate (Table 1). However, the mature paripinnate leaves were randomly distributed on the different parts of the plant as were both immature and old mature leaves.

When the plants were reassessed after two years, there were no statistically significant differences among the numbers of immature and mature leaves of the two types neither on the stem nor on the different branches. Therefore, the data from the stem and all branches on each plant were combined. This analysis revealed small but statistically significant differences in the number of mature paripinnate leaves per plant among the sites and in the numbers of immature intermediate leaves between the sites (Table 2). There were no differences among sites in the numbers of immature paripinnate leaves, nor mature intermediate leaves.

Leaflet Shape

Leaflet shapes of *M. exotica* are generally elliptical to obovate (Fig. 2); however, orbicular and obcordate leaflets were occasionally found (Fig. 3). The number and position of the obcordate leaflets varied among individuals (Fig. 4). In any one compound leaf, all leaflets may be obcordate, but there were also occurrences where only one, two or three obcordate leaflets were produced. The occurrence of obcordate leaflets was found in all populations observed; however, there were no differences in the number of leaves with obcordate leaflets at any site at any time of measurement. The one-year-old plants at PBG, UGM and BBG had between 5-6 obcordate leaves per plant. The three-year-old plants at these sites had between 4-6 obcordate leaves per plant and, when these plants were assessed two year later, they had between 4-8 obcordate leaves per plant. The plants grown at Purworejo had ~3.2 obcordate leaves per plant.

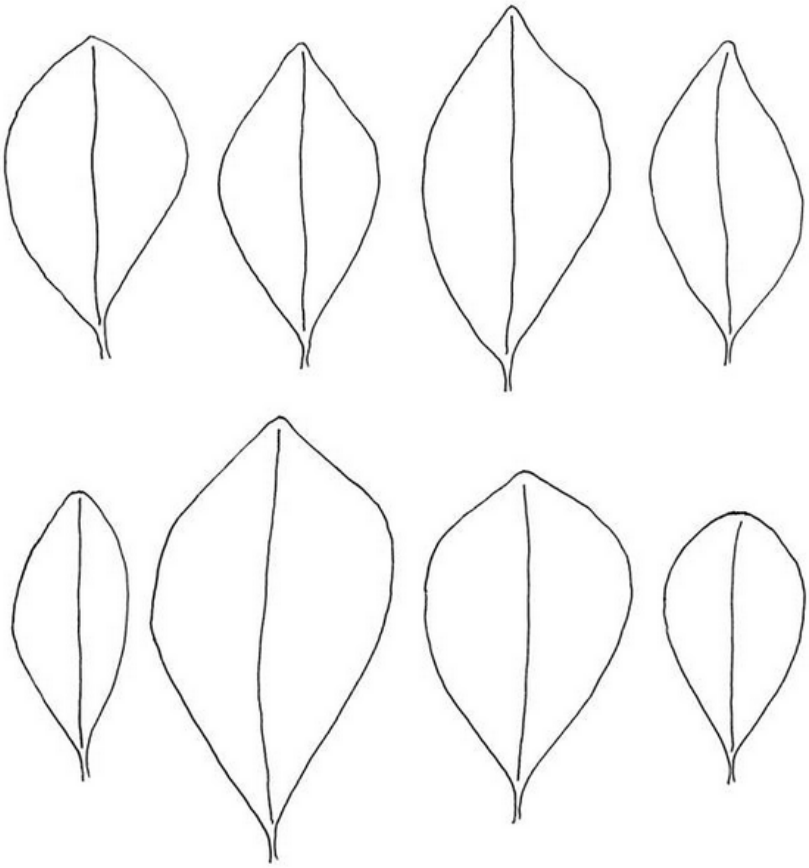

Fig. 2. Variation in shape of leaflets of *Murraya exotica*

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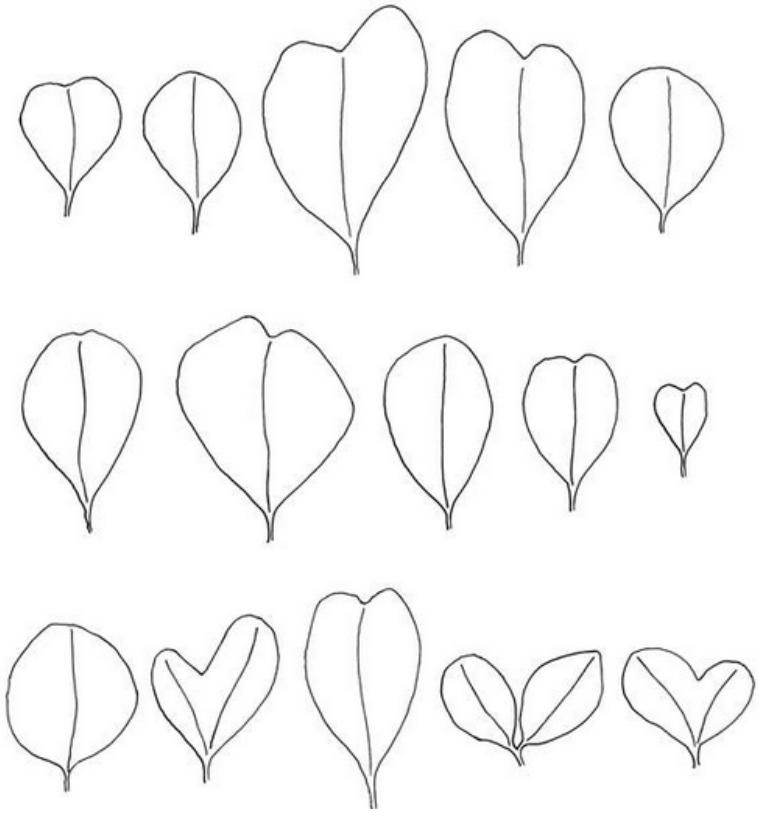

Fig. 3. Variation in shape of obcordate leaflets occasionally found on *Murraya exotica*

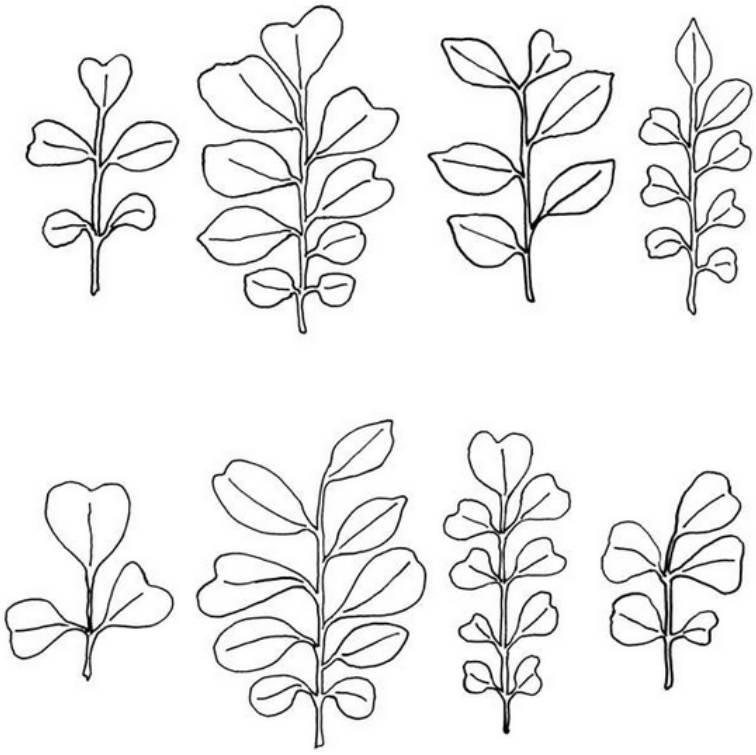

Fig. 4. Structure of leaves containing obcordate leaflets

Table 1. Average number of immature and mature paripinnate and intermediate leaves on the main stem and four side branches of three-year-old *Murraya exotica* plants. The averages are combined data from plants grown at Bogor and Purwodadi Botanical Gardens and at Universitas Gadjah Mada. Means within a leaf type followed by the same letter are not significantly different according to Fisher's LSD test at p = 0.05

	Paripinnate		Intermediate	
	Immature	Mature	Immature	Mature
Stem	2.13[a]	3.73[ab]	1.67[a]	3.33[b]
Branch 1	2.07[a]	3.73[ab]	1.60[a]	4.33[a]
Branch 2	1.40[b]	3.33[ab]	2.07[a]	4.13[ab]
Branch 3	1.47[b]	3.00[b]	1.80[a]	3.80[ab]
Branch 4	1.40[b]	4.07[a]	2.13[a]	3.47[b]

Table 2. Average number of immature and mature paripinnate and intermediate leaves on five-year-old *Murraya exotica* plants grown at different locations. The averages are combined data from the stem and all branches on the plants. Means within a column followed by the same letter are not significantly different according to Fisher's LSD test at p = 0.05

	Paripinnate		Intermediate	
Site	Immature	Mature	Immature	Mature
Purworejo	1.40[a]	4.40[c]	1.17[b]	5.27[a]
Purwodadi botanical gardens	1.30[a]	5.17[ab]	1.23[b]	5.17[a]
Bogor botanical gardens	1.80[a]	4.87[bc]	1.40[b]	5.67[a]
Universitas Gadjah Mada	1.70[a]	5.73[a]	2.07[a]	5.70[a]

Discussion

Tanaka (1929) described *M. exotica* as having unequally pinnate leaves consisting of 3, 5 or 7 alternate leaflets, obtusely acuminate at the apex, acuminate or tapering at the base. Swingle and Reece (1967) described *M. paniculata* (with *M. exotica* cited as a synonym) as producing unpaired-pinnate or occasionally pinnately 3-foliolate leaves with alternate, cuneate-obovate or almost obliquely rhomboid, blunt or bluntish acuminate leaflets. Stone (1985) described the genus as possessing alternate, imparipinnate leaves and described the leaves of *M. exotica* as having 3-7 leaflets that are alternate or the lowest pair opposite mostly obovate to subelliptic, obtuse to bluntly acuminate with the apex minutely notched. Stone (1985) described the leaves of *M. paniculata* as being alternate, imparipinnate, with 3-5 (rarely 7) leaflets and the leaflets, as being ovate or ovate-elliptic, acuminate, at the base cuneate to orbicular. The descriptions of these two species by Huang (1997) are broadly similar to those of Stone (1985). Our study is the first to report obcordate leaflets and the occurrence of paripinnate and intermediate leaves in either *M. exotica* or in *M. paniculata*.

Variation in leaf shape within a plant has been well documented and has been assigned to a number of different causes. There can be differences between immature and mature leaves, a phenomenon termed heteroblasty (Kersetter and Poethig, 1998). However, many plants have the ability to develop leaves of different shape in response to environmental conditions such as nutrient availability (Sussex and Cutter, 1960) and light (Njoku, 1956) and the evolutionary significance of this has been reviewed by Bradshaw (1965). In addition, phenotypic variability may be due to random interactions between genes and the environment (Mather, 1953) and this has been termed developmental noise by Waddington (1957). The cause of the variation in leaf type and leaflet shape and whether these features have a genetic component in *M. exotica* has yet to be determined. The variation in leaf type or leaflet shape observed in this study may be due to prevailing environmental conditions directing leaf development, thus a particular stress such as drought or high temperature may lead to particular leaf morphology. However, as there appears to be little difference between populations of *M. exotica* nor between different parts of individual plants in the number of paripinnate or intermediate leaves produced nor in the number of obcordate leaflets it may be that leaf development in *M. exotica* is particularly susceptible to developmental noise.

Conclusion

Heterophylly in populations of *Murraya exotica* resulted in three types of compound leaves (paripinnate, imparipinnate and intermediate) and three types of leaflet shape (oblong, rounded and obcordate) on both juvenile and adult plants. This variation may be due to the environmental conditions prevailing at the time of leaf production or due to developmental noise caused by random interactions between genes and the environment.

Acknowledgment

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Authors' Contributions

The practical work was conducted by IPA, The statistical analysis was perfomed by PH. All authors contributed to the design of the study and interpretation of data.

Ethics

There are no ethical issues associated with the content of this article.

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