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The differences in floral structures of three sandalwood variants in one of Gunung Sewu (Indonesia) population, and their consequences on visitor diversity and visitation rate

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Abstract. *Fathin AN, Ratnaningrum YWN. 2018. The differences in floral structures of three sandalwood variants in one of Gunung Sewu (Indonesia) population, and their consequences on visitor diversity and visitation rate. Biodiversitas 19: 1097-1101.* Sandalwood, one of the most economically valuable endangered species, is native to the southeastern Indonesian islands, but it has recently occurred as new landraces in Gunung Sewu, Java island. Our previous findings found three floral variants (YBF, refers to "yellow big flower"; RBF, "red big flower"; and RSF, "red small flower", respectively) of sandalwood landraces in Gunung Sewu. The differences in floral structures among variants were also reported. In this study, we further analyzed these variant differences and their consequences on visitor diversity and visitation rate in the Bleberan population, one of the most genetically diverse populations in Gunung Sewu Geopark, in the 2016 flowering period. Floral visitor diversity, visitation rate, and pollination behavior were observed in each floral variant. Visitor preference to a certain variant might be attributed to the differences in floral color and size. YBF was visited more by coleopterans and hemipterans, while both RBF and RSF were visited more by hymenopterans. The dipterans and lepidopterans visited both yellow and red flowers at a similar rate. The bigger flowers of RBF and YBF received more visits than RSF.

Keywords: Bleberan population, sandalwood floral variants, visitor diversity, visitation rate

INTRODUCTION

The components of floral traits, such as plant size, plant age (Torres et al. 2002), floral structures (Herlihy and Eckert 2005; Arroyo et al. 2006; da Cruz et al. 2006) and the arrangement of sexual organs (da Cruz et al. 2006; Ortigoza and Gomez 2009; Tamla et al. 2012), altogether determine floral display within population. The differences in this floral display components may have considerable effects on the species of pollinators and pollinator behavior, which in turn affect mating systems (Barrett et al. 2006), genetic diversity (Arroyo et al. 2006), reproductive outputs (Wolf et al. 2001; Fernandez et al. 2009) and the fitness of individuals (da Cruz et al. 2006) within a population. Furthermore, these internal traits may exhibit different responses to the environmental triggers (da Cruz et al. 2006; Bertin 2008; del Cacho et al. 2013; Richardson et al. 2013; Agullo et al. 2015).

A long term researches showed strong evidence that the Outer Arc of Banda Islands, now the southeastern Indonesian archipelago, is the center of origin of sandalwood worldwide (Angadi et al. 1993; Harbaugh and Baldwin 2007; Rao et al. 2007; da Silva et al. 2016). An economically-important species, *Santalum album* Linn (Santalaceae), herein after referred to as sandalwood, produces heartwood containing 1.5 to 5% of β-santalol, a strong, specific fragrance of oil, which has been widely used for wood carving, art, religious and medicinal purposes. Its oil is the material of cosmetics, prime source for perfumes and aroma-therapy, and is thought to contain anti-melanoma compounds (Rao et al. 2007; da Silva et al. 2016). Australia, India, and Indonesia were previously among the main exporters of sandalwood's wood and oil (Angadi 1993; Rao et al. 2007), but the population of this species has declined rapidly within the last three decades (Angadi et al. 1993; Suma and Balasundaran 2003; Rughkla et al. 2006; Rao et al. 2007; Dani et al. 2011; Indrioko and Ratnaningrum 2015; da Silva et al. 2016), and since 2004, Indonesia no longer participates in the worlds' trade of sandalwood (MoF 2012). Considering the significant habitat degradation and loss, this species was first listed as *vulnerable* in the IUCN Red List of Endangered Species in 1994 (IUCN 1994); in addition, it is protected by national law (MoF 2012; Indrioko and Ratnaningrum 2015). Since the habitat loss has dramatically increased within less than a decade, the *vulnerable* status might be raised to *endangered* or even *critically endangered* (IUCN 2009). It is even considered *extinct in the wild* in most of its native habitat in southeastern Indonesian islands (MoF 2012; Indrioko and Ratnaningrum 2015).

While a significant population decline is happening in their native habitat in the southeastern Indonesian islands, new landraces of sandalwood have emerged in Gunung Sewu Geopark, a 1300 km^2 mountainous limestone zones in the central part of Java island (Ratnaningrum et al. 2015,

2017). Considering the rapid population decline in their origin, the occurrence of these new landraces sounds promising for any reintroduction and rehabilitation efforts. Sandalwood in Gunung Sewu spreads along geographical gradients under various types of landscapes. Out of nine populations observed, Bleberan possesses the highest genetic diversity, and therefore put under consideration for the center of germplasms in the future (Ratnaningrum et al. 2015). Our preliminary studies reported that each population in Gunung Sewu consisted of at least three sandal variants (YBF, refers to "yellow big flower"; RBF, "red big flower"; and RSF, "red small flower", respectively) distinguished by floral structures and longevity. These variant differences were considered to be under genetic controls (Ratnaningrum et al. 2017). Our previous studies also found evidence of mating constraints, since some populations failed to produce mature fruits (Indrioko and Ratnaningrum 2015). Many other studies in sandalwood showed evidence that differences in floral structures affect the mating systems, which in turn result in different pollination success (Sindhu-Vereendra and Anantha-Padmanabha 1996; Suma and Balasundaran 2003; Rughkla et al. 2006; Tamla et al. 2012; Ratnaningrum and Indrioko 2015). Furthermore, such differences in floral sexual organs may affect pollination processes which in turn result in mating incompatibility, as reported for *S. album* in India (Rughkla et al. 2006; Suma and Balasundaran 2003), *S. album, S. lanceolatum* and *S. spicatum* in Western Australia (Tamla et al. 2012) and *S. lanceolatum* in Victoria Australia (Warburton et al. 2000). This study compared floral variants of sandalwood and their effects on pollination activities, in Bleberan population of Gunung Sewu Geopark, in the 2016 flowering period.

MATERIALS AND METHODS

Study site

Bleberan (150-170 m asl.) is a part of Wonosari Basin Formation in the Middle Zone of Gunung Sewu, Southern part of Java Island, Indonesia. Recently it exists as the catchment area of the ancient subterranean Oya River at the lowland basin landscapes, represents the tropical lowland ecosystems, in the intermediate between *Aw* and *Am* types. The population of sandalwood is located in a basin area that receives abundant rainfall (2346 mm annually in 2 to 6 rainy months). Therefore, it possesses the intermediate of *Am* and *Aw* climatic types with high temperature (34.37°C) and light intensity, having relatively high soil moisture (27.33%) and relative humidity (58.36%). The soils are the association of red mediterrans and black grumusols with limestone rocks, mostly with the deep solum. Sandalwood was first documented in the 1970s along the riparian area of the ancient subterranean Oya River, at the lowland basin of middle zone. Recently, sandalwood occupies more than 52 ha land, along with the riparian area and nearby, in association with the tropical lowland forest which is composed of diverse species, including teak, mahogany, *Gliricidia* sp, *Schleichera* sp, cajuput and acacia. The population is surrounded by several ex situ conservation areas which share the same river.

Study species

Our preliminary study divided sandalwood in Gunung Sewu into three variants (YBF, refers to "yellow big flower"; RBF, "red big flower"; and RSF, "red small flower", respectively), distinguished by their floral traits, with regard to the floral color, structures, arrangements and the longevity of sexual organs (Figure 1). The RSF and RBF are dominated by red and maroon colors, while YBF is more yellowish to orange. The RBF and YBF have bigger perigonium, longer size of sexual organs with similar/lower position of stylus to the stamens, and possess shorter longevity. RSF flowers are smaller, stylus is similar/higher than the anthers, and have greater longevity. In our preliminary study, sandalwood flowered twice a year in all of sites and variants, however the onset and duration varied. YBF flowered earliest while RBF was the latest. RSF possessed the longest flowering period. Flowering and floral structure differences among variants were considered to be under genetic controls, while the variation among sites was affected more by environmental differences. Flowering varied among sites due to the altitude, edaphic and climatic differences. Sandalwood in lower altitude, drier and warmer sites flowered earlier and shorter (more detailed data on floral structures, sexual organs longevity and flowering phenology of these three variants are available at Ratnaningrum et al. 2017).

Pollinators and pollination observation

Observation was carried out over 60 hours, spread across a peak flowering period in the dry season of 2016. Pollinator activities were quantified, whereby independent observers simultaneously monitored visitation at nine points, with three flowering trees per point (total N = 3 points x 3 variants x 3 flowering trees = 27 trees), for a period of 12 hours per day (started from 05: 00 am to 05: 00 pm), over a total of five days of the peak flowering period (Machado and Sazima 2008; Borges et al. 2009). For this pollinator observation purpose, the total number of single flowers referred to the sum of all flowers produced by the nine sampled trees of each variant at each site. The type and abundance of flower visitors were recorded. Visitation rate, which referred to the number of visits per given time period (da Cruz et al. 2006), was measured for each type of flower visitors. The visiting insects were captured for pollen load observation and dry mounted for identification in the Entomological Laboratory, Faculty of Agriculture, Universitas Gadjah Mada.

RESULTS AND DISCUSSION

Results

Visitor preference varied with floral variants, which might be attributed to the differences in floral color and size. Visitation in the yellow flowers of YBF variant was dominated by coleopterans and hemipterans, while the red flowers of both RBF and RSF were visited more by

hymenopterans. The dipterans and lepidopterans visited both yellow and red flowers in a similar visitation rate. The bigger flowers of RBF and YBF received more visits than RSF, the smaller ones (Figure 2.A).

Visitor preference was thought to be determined by the floral structures and colors. The yellow flowers of YBF variant were visited more by Lepidopterans belonging to the moth groups: Arctiidae, Hesperiidae, and Noctuiidae. In contrast, Lepidopterans belonging to the butterflies groups (Papillionidae, Nymphalidae, and Pieridae) preferred to visit the red flowers of RBF and RSF. All six families of Hymenopterans (Figure 2.D) preferred to visit the red flowers with bigger size, RBF. In contrast, all four families of Coleopterans (Figure 2.E), as well as the four families of Hemipterans (Figure 2.F), preferred the yellow flowers of YBF. All four families of Dipterans made similar visits to both RBF and YBF, but the visitation was less in RSF (Figure 2.B).

Figure 1. Three sandalwood floral variants in Gunung Sewu, Midden Java, Indonesia: A. YBF, refers to "yellow big flower"; B. RBF, "red big flower"; C. RSF, "red small flower"

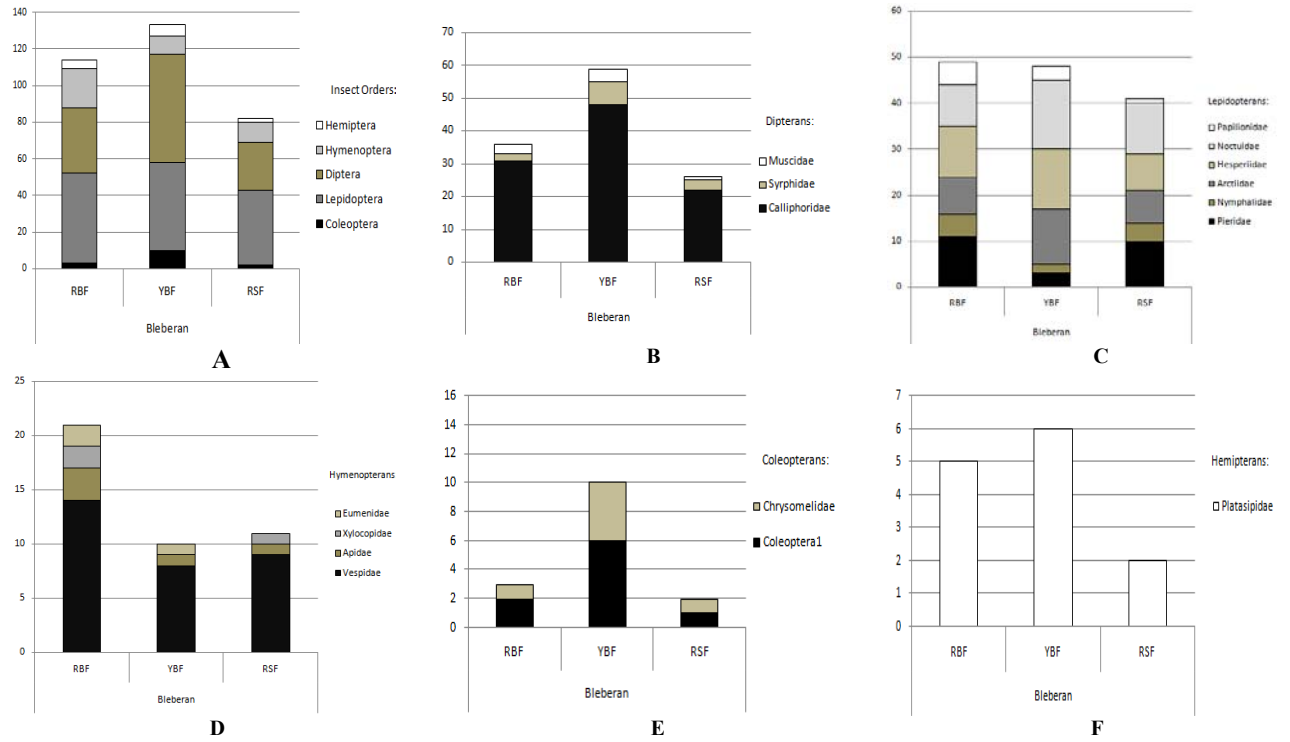

Figure 2. The visitor diversity at the Order (A) level, and at the family levels within the Order of Dipterans (B), Lepidopterans (C), Hymenopterans (D), Coleopterans (E) and Hemipterans (F), respectively, in three sandalwood variants in Bleberan population, Gunung Sewu, Southern Java, Indonesia

Discussion

Visitor preference to certain floral variants might be attributed to the differences in floral color and size. Visitation in the yellow flowers of YBF variant was dominated by coleopterans and hemipterans, while the red flowers of both RBF and RSF were visited more by hymenopterans. Meanwhile, the dipterans and lepidopterans visited both yellow and red flowers in a similar visitation rate. The bigger flowers of RBF and YBF received more visits than RSF, the smaller ones. Many similar works also consider that the visitation of different visitors within the same plant species is related to their preference to visit a certain floral color. The bees are attracted by the white and blue colors and prefer to visit the flowers with the "*fresh and not-very-strong odor"*; while most of Lepidopterans prefer the brighter color such as red and bright-yellow (Jones and Little 1983; Griffin and Sedgley 1989; Ghazoul 1997). Purple flowers are widely thought to be a feature of the bee-pollination, while the paler color, such as yellow and white, attract the dipterans (Ortigoza and Gomez 2009). The visitor selection of flowers may be determined by sight, but the decision to visit is determined more by odor. These color and odor are used by insects as a cue to the availability of rewards (Jones and Little 1983).

As was reported in this study, many types of research also found different floral colors in the same plant species, which consequentially result in the different pollinator diversity and abundance. A very similar finding to this study was reported with *Erysimum* species in Sierra Nevada, Spain, in which the bees preferred the purple flowers, and ignored the yellow ones which were visited more by flies (Ortigoza and Gomez 2009). The purple flowers of *Cirsium palustre* were visited by bumblebee *Bombus lapponicus*, while white flowers were visited more by moths and flies. Same findings were also reported with *Raphanus raphanistrum* whose yellowish purple flowers were visited by *Bombus* spp, while flies and moths preferred the white ones (Jones and Little 1983).

Several researchers compiled observation results on the differences of visitors among the different floral color and rewards availability (Jones and Little 1983). The Hymenopteran *Anthophora pilipes* (Anthophoridae) intensively visit the pink flowers of *Pulmonaria officinalis* (Boraginaceae) but ignores the blue ones. The blue flowers are visited more often in Mertensia (Boraginaceae) and Oxytropis (Fabaceae). The bumblebees (*Bombus* sp) ignore the red flowers of *Aesculus hipocastanum* (Hippocastanaceae) and prefer the bright-yellow ones. The Dipteran *Eristalis tenax* prefers pale off-white *Senecio jacobaea* flowers and avoids the dark brown ones. In *Solidago spathulata*, visitation of Dipterans is mostly occurred when the corolla is purple, indicating the availability of nectars and pollen. In *Lantana* spp in Brazilia and Calcutta, Lepidopterans prefer to visit yellow and orange flowers providing abundant nectars, and completely ignore the dark purple ones. In *Leavenworthia crassa*, honeybees favor yellow flowers while flies prefer only the off-white ones.

As was also reported in this study, sandal flowers have evolved both spatial-and temporal-separation of sexes, such a mechanism to separate reproductive structures in order to prevent inbreeding. Temporal separation of sexes is exhibited by dichogamous-protandrous mechanism which separates the timing of sexual organs maturity (Sindhu-Vereendra and Anantha-Padmanabha 1996; Suma and Balasundaran 2003; Rughkla et al. 2006; Tamla et al. 2012; Ratnaningrum and Indrioko 2014; Ratnaningrum et al. 2016, 2017). In addition, spatial separation of sexes is possessed by heterostylous and heteranthery type of flowers, such a positional difference of anthers relative to the stigmatic level. In case of *S. album* flowers, some individuals produce flowers with style at, or slightly below, the level of the top of the anthers, while some other individuals possess higher style than the anthers (Sindhu-Vereendra and Anantha-Padmanabha 1996; Rughkla et al. 2006; Tamla et al. 2012; Ratnaningrum and Indrioko 2014; Ratnaningrum et al. 2017).

Size of corolla, length of filament and anthers position are positively correlated with the intensity of pollen transferred. Hence the heterostylous and heteranthery flowers tend to be more outcrosser. The differences in the size of reproductive structures on twenty-five biotically pollinated plants of the Chaco Serrano Forest, Argentina, resulted in the differences of reproductive outputs; in which the smaller and heterostylous flowers tended to produce more seeds (Fernandez et al. 2009). The mating systems of narrow endemic *Anthirrhinum microphyllum* are also strongly related to the characters of sexual organs, in which smaller and heterostylous flowers are more outcrosser (Torres et al. 2002). Other studies reported reproductive failure in *Ipomea aggregata,* which could be attributed more to the mechanical barrier of pollination due to the difference in stylus length (Wolf et al. 2001). More studies are needed to reveal the differences in reproductive outputs in sandalwood as a result of the differences in size and structures of sexual organs.

In conclusion, visitor preference varied with the floral variants, which might be attributed to the differences in floral color and size. Visitation in the yellow flowers of YBF was dominated by coleopterans and hemipterans, while the red flowers of both RBF and RSF were visited more by hymenopterans. Meanwhile, the dipterans and lepidopterans visited both yellow and red flowers in a similar visitation rate. The bigger flowers of RBF and YBF received more visits than RSF, the smaller ones.

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