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Heritability and Combining Ability of Some Vegetative and Yield Characteristics of Promising Arabica Coffee Varieties in Indonesia

Ari Wibowo[1*)], Miftahur Rizqi Akbar[1)], and Ucu Sumirat[1)]

[1)]Indonesian Coffee and Cocoa Research Institute, Jl. PB Sudirman No.90, Jember, Indonesia
[*]Corresponding author: ariwibowo.iccri@gmail.com
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Abstract

Hybridization is one of the methods to create a source of plant genetic diversity that superior genotypes can be selected from these genetic variations. Quantitative genetics enhance the precision of plant selection to achieve the breeding objectives. This research aimed to evaluate the heritability and combining ability of Arabica coffee crossing over progenies. This study used a completely randomized design with three replications and was carried out at the Andungsari Experimental Station, Bondowoso, East Java, Indonesia. The materials consisted of five Arabica parents, namely BP 542A, P 88, S 795, Hibrido de Timor (HdT), Geisha, and ten F1 offsprings from the hybridization. Data observed included leaf size, internode length, fruit size, cluster number per branch, and number of fruits per branch. The analysis was based on Griffing's Model II using MS. Office Excel 2016. The results showed that leaf width had a high narrow-sense heritability. Meanwhile, S 795 and Geisha parents had high general combining ability in internode length, cluster number, and fruit number per branch. The high specific combining ability values for fruit size and leaf size were shown by the combination of BP 542A x S 795 and P 88 x S 795. Meanwhile, the cross of S 795 x HdT showed a high specific combining ability for internode length, cluster number, and fruit number per branch. From this crossing combinations, high yielding genotypes potentially can be obtained.

Keywords: promising coffee lines, genetic variability, high yielding

INTRODUCTION

Coffee consumption in Indonesia increased by 7.8% in the period of 2015-2018 (ICO, 2018; Wibowo, 2019), leading to the increasing in demand for coffee. The availability of new superior planting materials with wide adaptability throughout the country become the main solution to increase coffee production. Indonesian Coffee and Cocoa Research Institute (ICCRI) as a research and development institution for coffee planting materials in Indonesia, always provides national stakeholders the superior materials. Komasti was the latest variety released in 2013 as a national superior planting material as a result of breeding activities (Mentan, 2013). Efforts to produce superior planting materials will continue and one of them is by hybridization (Hulupi, 2008). The crossing over of Arabica superior parents has been one of the methods to produce high genotypic diversity before the selection process. The offspring selection to determine superior genotypes can be carried out through genetic studies on the combining ability calculated from the results of a diallel cross (Griffing, 1956). Genetic studies of hybridization on Arabica coffee plants are still rarely carried out because the hybridization process takes a long time. For example, ICCRI breeders need around 20 years to release superior Robusta coffee varieties from plant hybridization (Puslitkoka, 2018).

Diallel crosses can produce high genetic diversity (Saputra *et al*., 2014). The genetic analysis results can be used as guidelines for evaluating the genetic potential of a superior genotype (Budiyanti *et al*., 2017). Diallel crosses are also able to provide information about the genetic controller of the evaluated characters (Teodoro *et al*., 2019). The initial stage evaluating the hybridization results is analysing the combining ability value. By analysis of the combining ability makes it easier to determine the best combination of parents for crosses. This method is beneficial to decide which gene plays a role in expressing the desired trait and determining the breeding method to be used. Combining ability is defined as the ability of genotypes or parents to produce the best combination during the hybridization process so that the desired character or trait is passed on to the next generation (Fasahat *et al*., 2016).

General combining ability (GCA) estimation helps to select the best parents, while specific combining ability (SCA) estimation helps to reveal the best combination of hybridization parents to get F1 hybrids (Hulupi, 2008; Iriany *et al*., 2011; Ayano *et al*., 2015; Teixeira *et al*., 2017). GCA is directly related to the breeding value of a parent and is associated with additive genetic effects, while SCA is the relative performance of a cross that is associated with non-additive gene action (Bautista *et al*., 2018; Teodoro *et al*., 2019) and both play an important role in the heterosis value (Zhang *et al*., 2015; Teixeira *et al*., 2017). Combining ability estimation provides information about the best parent combination to produce better offspring. If the combined ability values are used to select the parents, heritability determines the selection criteria. Heritability is a basic science in genetics and is used to determine the effectiveness of selection characters (Evans *et al*., 2018) in plant breeding programs. In addition, with the early selection of parents, the long selection time of perennial plants can be shortened. This experiment is crucial to obtain information about the potential of Arabica coffee genotypes as a better genetic improvement material. This study aimed to determine the combining ability and heritability value of the morphological characters of coffee plants through a diallelic cross of five Arabica coffee varieties.

MATERIALS AND METHODS

The cross involved five parents, namely BP 542A, P 88, S 795, Hibrido de Timor, and Geisha, conducted from 1999 to 2002 (carried out by Dr. Surip Mawardi and Dr. Retno Hulupi). The BP 542A has high productivity (2.1 tons ha^{-1}) and is considered to be resistant to parasitic nematodes. P 88 has excellent taste and is inferred to be resistant to parasitic nematodes as well (Hulupi *et al*., 2013). S 795 variety has a high number of internodes (11 internodes per branch), very good tastes, and has large fruit size (Hulupi, 2016). Hybrido de Timor (HdT) results from a natural cross between Arabica and Robusta coffee and is acknowledged to be resistant to parasitic nematodes, while Geisha has excellent taste. The hybridization between Arabica coffee parents is expected to produce offsprings with high production characteristics, good taste, and moderate resistance to parasitic nematodes. The progenies of the crosses were planted in 2003 in plot C4 of the Andungsari Experimental Station, Bondowoso Regency, East Java. The experimental site is located at an altitude of 1,400 m asl. The planting materials were planted at a distance of 2.5 m x 2.5 m. Permanent shade of *Leucaena leucocephala* arranged at a distance of 2.5 m x 2.5 m spacing at a diagonal of coffee rows. The coffee plants were maintained with a two-stage single stem pruning system. Observations of the genotypes were carried out from February to March 2021, and the daily temperature at the experimental site ranged from 14ºC-22ºC, and the average rainfall was 94.7 mm month^{-1} in 2020 (BPS, 2021). The climate at the site is C type, according to the climate classification of Schmidt and Ferguson (Hulupi *et al*., 2012).

The experiment used diallel Griffing method Model II resulted in 10 combinations of F1 crosses and five observed parents of the crosses. The research design used was a single-factor completely randomized design, namely plant genotypes as treatment factor replicated three times. There were 45 experimental units. Each experimental unit consisted of three coffee plants. Variables observed included the vegetative characters, namely leaf size and internode length, and generative characters, namely fruit size, fruit thickness, cluster number per branch, and fruits number per branch. The estimated general combining ability (GCA), specific combining ability (SCA), and narrow-sense heritability were analyzed using Griffing's method Model II (Singh & Chaudhary, 1979) and calculated in MS Office Excel 2016.

RESULTS AND DISCUSSION

Estimated GCA

Morphological characters are often used as an early guidance to determine the genotypic variation in the crossing progenies. These characters are easy to observe, so the estimation of genotypic variation can be done even though environmental influences may present. In coffee plants, quantitative data that can be used for markers of genotypic variation were number of primary branches, number of internodes per branch, internode length, fruit number per cluster, and weight of 100 cherries (Muvunyi *et al*., 2017). The analysis of variance showed that genotype had a significant effect ($p<0.05$) on leaf length, cluster number per branch, and number of fruits per branch. Genotype also had a significant effect ($p<0.01$) on leaf width, internode length, and fruit size (length, width, and thickness). The same results were also shown by 30 promising clones of Robusta coffee crosses (Giles *et al*., 2018). Each promising clone showed different morphological characters in leaf size, internode length, and plant yield. GCA estimation also showed a significant effect ($p<0.05$) on the leaf width, internode length, fruit length, fruit width, cluster number, and number of fruits per branch. GCA analysis on cocoa plants also showed that GCA had a significant effect on the vegetative character of the plant (Suhendi *et al*., 2004). SCA also significantly affected ($p<0.05$) the internode length, fruit size, and the number of fruits per branch (Table 1). The analysis results of combining ability indicated that the action of additive and dominant genes plays a importent role in decreasing traits in observed characters (Iriany *et al*., 2011; Ayano *et al*., 2015; Bautista *et al*., 2018). In the observed Arabica coffee, the internode length, fruit length and width, and the fruits number per branch were controlled by additive and dominant gene action.

BP 542A has high production potential (2.1 tons ha^{-1}), P 88, S 795, and Geisha have excellent taste, and HdT has good resistance to leaf rust and parasitic nematodes. A cross between BP 542A parent and one of the parents with excellent taste (P 88, S 795, Geisha) is expected to create Arabica coffee offspring with high productivity and excellent taste, while with the HdT parent it is expected to produce offspring with high production potential and good taste while tolerant to pest and disease attacks.

Table 1. Analysis of variance on the morphological characters of Arabica coffee

Source of variation	d.f.	Mean square							
		Leaf length	Leaf width	Internode length	Fruit length	Fruit width	Fruit thickness	Cherry cluster number per branch	Number of fruits per branch
Replication	2	1.370 *	0.233	0.174	0.571	0.099	0.125	0.103	0.369
Genotype	14	0.833 *	0.647 **	4.017 **	1.363 **	0.995 **	0.890 **	1.224 *	99.091 *
GCA	4	0.323	0.560 **	2.182 **	0.515 **	0.292 **	0.108	0.561 *	34.877 *
SCA	10	0.259	0.078	1.002 **	0.430 **	0.347 **	0.372 **	0.347	32.292 *
Errors	28	0.366	0.166	0.298	0.295	0.103	0.130	0.541	37.440

Note: d.f.= degree of freedom; GCA = general combining ability; SCA = specific combining ability; (*) indicates a significant difference at $p<0.05$ and (**) shows a significant difference at $p<0.01$

BP 542A had a positive GCA value on the fruit length and fruit width. P 88 had a positive GCA value on leaf length, leaf width, fruit width, and fruit thickness. S 795 had a positive GCA value for leaf length, internode length, cluster number, and number of fruits per branch. HdT had a positive GCA value on internode length and fruit thickness. Geisha had a positive GCA value on the internode length, cluster number, and the number of fruits per branch (Table 2). Based on the GCA analysis, BP 542A is the best combiner for fruit size; P 88 is the best combiner for leaf size and fruit width; S 795 is the best combiner for internode length, cluster number, and number of fruits per branch; Geisha is the best combiner for internode length (Table 2). BP 542A had a positive GCA value for fruit size and a negative GCA value for the number of fruits per branch, while S 795 had opposite GCA values for these two characters. In contrast to these results, in tomato plants, parents with small fruit sizes had positive GCA values and negative fruit number (Saputra *et al.*, 2014).

The first step to get superior offspring from hybridization in the plant breeding program is to select the potential genotypes as parental lines. It is selected from a large number of genotypes based on the GCA effect evaluation of the desired characters. Superior hybrid offsprings can be expected based on the GCA and SCA values (Gowda *et al.*, 2012). Parents with positive and high GCA values are the best combiners when hybridized with other parents, while negative GCA values indicate that the tested genotype contributed to decreased observed character diversity (Budiyanti *et al.*, 2017). The highly and positively GCA parents have the potential to produce vigorous hybrid plants (Saputra *et al.*, 2014; Ayano *et al.*, 2014), have a good inheritance to offspring (Fasahat *et al.*, 2016), and have the potential for development of pure line varieties (Han *et al.*, 2020). However, if a breeding program aims to produce offspring resistant to pests and diseases, parents with low GCA values are selected for that character.

The analysis results showed that S 795 and Geisha had positive GCA values for internode length, cluster number, and the fruits number per branch. The two parents can be the best combiners. The highly and positively GCA parents can be an alternative as female parents (Gowda *et al.*, 2012; Han *et al.*, 2020). To obtain a high-yielding Arabica coffee genotype, the character of the internode length and the cluster number can be the initial selection criteria (Idol & Youkhana, 2019). The basis for selecting these characters is that the dwarf type Arabica variety has more cherry clusters and a higher fruit production potential than tall type Arabica coffee (Hulupi, 2016). In addition, the internode length character is also positively correlated with the number of fruits per plant (Muvunyi *et al.*, 2017). High productivity has always

Table 2. The general combining ability of five parental lines

Genotype	Leaf length	Leaf width	Internode length	Fruit length	Fruit width	Fruit thickness	Cherry cluster number per branch	Number of fruits per branch
BP 542A	-0.323	-0.062	-0.677	0.413	0.043	-0.058	-0.161	-0.808
P 88	0.186	0.490	-0.506	-0.008	0.326	0.180	-0.302	-2.240
S 795	0.208	-0.202	0.409	-0.349	-0.178	-0.146	0.448	3.587
HdT	-0.026	-0.045	0.207	-0.043	-0.029	0.058	-0.028	-1.059
Geisha	-0.044	-0.181	0.568	-0.014	-0.162	-0.034	0.042	0.521

been the main criterion in Arabica coffee breeding and is a requirement in releasing national superior planting material.

Estimated SCA

Superior F1 hybrids can be obtained from the crosses among selected genotypes. High SCA is used as a guideline to determine the best combination of hybrid crosses because it produces offspring with highly heterosis (Marcon *et al*., 2020). High SCA values are generally produced from parents with high GCA values (Saputra *et al*., 2014), but this research shows that not all combinations of crosses using the high and positive GCA parents can produce high SCA values. For example, hybridization between P 88 and HdT parents with a positive value for GCA fruit thickness could produce a negative SCA value for the same character. Negative SCA results also occurred in the crosses of S 795 and Geisha parents on the number of clusters and the number of fruits per branch even though they had a positive GCA.

For leaf size (length and width), a cross between BP 542A x HdT was the best combination (positive SCA value and higher than the rest), while S 795 x HdT and S 795 x Geisha crosses were not recommended (negative SCA). S 795 showed positive GCA on fruit size when crossed with BP 542A, P 88, HdT, and Geisha parents, but the best cross combination was S 795 x HdT. The GCA values on the fruit length and width of S 795 and HdT were negative but able to produce the highest SCA value. The estimated SCA, as presented in Table 3, maybe resulting from the epistatic effect alleles (Iriany *et al*., 2011; Gowda *et al*., 2012). Another cause is the presence of non-allelic interactions and the heterozygous parental allele (Bautista *et al*., 2018). The combination of S 795 x HdT and HdT x Geisha was the best combination for the internode length, of which SCA are 1.106 and 2.019, respectively. The positive SCA values for number of clusters and number of fruits per branch belonged to the crosses of BP 542A x P 88, BP 542A x S 795, S 795 x HdT, and HdT x Geisha. For fruit size, a cross of BP 542A x S 795, P 88 x S 795, S 795 x HdT, and S 795 x Geisha were the best combinations. S 795 genotype was able to produce a positive SCA value when paired as a female parent or male parent even though it had a negative GCA value. In barley, crosses between parents with negative GCA on internode length were also able to produce positive SCA values (Zhang *et al*., 2015). Fasahat *et al*. (2016) explained that high GCA values indicate broad adaptability so that parents with highly GCA might not necessarily produce better hybrids. An epistatic effect was possible in the S 795 parent. Crossing over between S 795 and HdT was the best combination to produce the highest number of fruits per branch (Table 3).

Combining ability analysis is an index to measure the suitability of various characters in parents and is used as a basis for selecting parents (Han *et al*., 2020). High SCA values are also a basis for breeding using the recurrent selection method (Marcon *et al*., 2020). The creating of hybrid varieties is directed to obtain

Table 3. The specific combining ability of five combination crosses

Genotype	Leaf length	Leaf width	Internode length	Fruit length	Fruit width	Fruit thickness	Cherry cluster number per branch	Number of fruits per branch
BP 542A × P 88	-0.013	0.095	0.221	-0.134	0.424	0.437	0.076	0.244
BP 542A × S 795	0.521	0.149	-0.046	0.833	0.310	0.216	0.284	4.473
BP 542A × HdT	0.928	0.339	0.038	-1.196	0.192	0.407	-0.031	-3.020
BP 542A × Geisha	-0.012	-0.025	-0.955	-0.188	-0.502	-0.479	-0.601	-3.193
P 88 × S 795	0.436	0.048	-0.670	0.468	0.329	0.438	-0.450	2.759
P 88 × HdT	0.024	-0.040	0.034	-0.012	0.019	-0.004	-0.127	-4.303
P 88 × Geisha	0.111	0.131	-0.509	-0.040	0.038	0.199	-0.571	-5.789
S 795 × HdT	-0.227	-0.167	1.106	0.608	0.902	0.850	0.484	8.231
S 795 × Geisha	-0.084	-0.114	0.042	0.089	0.434	0.419	-0.918	-8.161
HdT × Geisha	-0.642	-0.583	2.019	-0.338	0.304	0.248	0.391	2.204

high-yielding offsprings. Observation parameters closely related to yield components are internode length, number of clusters, and number of fruits per branch. The crosses of S 795 x HdT x Geisha were the best combination for obtaining high-yielding F1 hybrid offspring. The selection approach through the estimation of GCA and SCA has been quite effective in producing superior offspring in coffee plants (Teixeira *et al*., 2017). The vigorous planting material for Robusta coffee (namely Hibiro 1–5) has been the variety result of coffee hybridization based on the estimation of SCA (Puslitkoka, 2018).

Estimated Heritability

The additive and dominant variance can be estimated using the GCA and SCA values. In self-pollinated plants, the additive variance is twice the GCA variance, while the dominant variance is the same as the SCA variance (Singh & Chaudhary, 1979). The higher the GCA variance, the greater the effect of additive genes on an observed character. The influence of dominant genes can be seen from the SCA variance (Saputra *et al*., 2014). The analysis results showed that the dominant variance values for leaf length, internode length, fruit size, number of clusters, and number of fruits per branch were higher than the additive variance.

Heritability is an approach to determine phenotypic variance calculated using a quantitative genetics. Using that results, a breeder can estimate the contribution of genetic values to phenotypic appearance (Evans *et al*., 2018; Athanasiadis *et al*., 2020). Heritability is divided into three groups: high (>0.5), moderate (0.2–0.5), and low (< 0.2) (Islam *et al*., 2012; Bhandari *et al*., 2017). The leaf width had a high heritability (0.78). The internode length and number of clusters in this research had moderate heritability (0.40 and 0.26). The leaf length, fruit length, and the number of fruits per branch had low heritability (Table 4). Low heritability for fruit length was reported in tomatoes and raspberries (Islam *et al*., 2012; Bautista *et al*., 2018). The number of fruits per plant showed high heritability on tomato plants (Bhandari *et al*., 2017). In Robusta coffee, the yield component (hulled coffee bean) has a high heritability estimate (Teixeira *et al*., 2017). Narrow-sense heritability is used to estimate the effect of additives on the phenotype (Athanasiadis *et al*., 2020). The morphological traits possessing high heritability, such as leaf width, have a more additive variation than the dominant variation. Low and medium narrow sense heritability values indicate that non-additive gene action plays an important role in the inheritance of traits (Bautista *et al*., 2018; El-Satar, 2017). The higher the narrow sense heritability value, the higher the possibility for a character to be inherited by the next generation (Saputra *et al*., 2014; Budiyanti *et al*., 2017). The leaf width had a high herita-

Table 4. Heritability values for the morphological characters of Arabica coffee

	Leaf length	Leaf width	Internode length	Fruit length	Fruit width	Fruit thickness	Cherry cluster number per branch	Number of fruits per branch
ó^{2}A	0.04	0.28	0.67	0.05	-0.03	-0.15	0.12	1.48
ó^{2}D	0.14	0.02	0.90	0.33	0.31	0.33	0.17	19.81
h^{2}ns	0.12	0.78	0.40	0.10	-0.10	-0.68	0.26	0.04

Note: ó^{2}A = additive variance; ó^{2}D = dominant variance; h^{2}ns = narrow-sense heritability.

bility (0.78). The internode length and number of clusters in Arabica coffee had a moderate heritability value (0.40 and 0.26). Leaf width has a high opportunity to be passed on the offsprings, while the productivity component has a low to medium level of inheritance.

The results help to formulate the direction of the next step for the Arabica coffee breeding program. The S795 and Geisha genotypes can be the best choice of parents to produce high-yield and excellent-taste offsprings. The hybridization results of the two parents can undergo recurrent selection to get expected superior planting material. Based on SCA estimation, the progenies of S 795 x HdT and HdT x Geisha crosses can be propagated as clonal plants. Development of the two genotypes can be used as promising clones of high-yielding Arabica coffee and tested using a multi-location trial before being released into new superior planting material.

CONCLUSIONS

The morphological traits of the internode length, fruit length, fruit width, and number of fruits per branch were controlled by additive and dominant gene action. P88 as a parent had high GCA for vegetative and generative characters (leaf length, leaf width, and fruit size). Recurrent selection can be made from hybridization of S 795 and Geisha as parents to obtain a new superior planting material. Combination of crosses between S 795 x HdT and HdT x Geisha was able to produce high SCA values for internode length, number of clusters, and number of fruits per branch. The offsprings can be propagated clonally and potentially become new high-yielding Arabica coffee clones. Leaf width had high heritability. The internode length and clusters number had medium heritability.

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