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Diallel Analysis using Hayman Method to Study Genetic Parameters of Yield Components in Pepper(*Capsicum annuum* L.)

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One method to obtain genetic information is the diallel cross analysis. The objective of this study was to eavluate the genetic parameters of six inbred pepper (*Capsicum annuum* L.) using full diallel crosses. The experiment was conducted at IPB Experiment Field, Cikabayan, Darmaga. The design was randomized complete block design (RCBD) using three replications as blocks. Data from generation F1 and parents were analyzed using the Hayman Method. Results indicated that no epistatic effects were significant for all the traits assessed. Additive genetic effects were larger than the dominant effects for yield per plant, fruit length, and diameter fruit traits. Dominant genetic effects were larger than the additive effects for fruit weight traits. Narrow-sense and broad-sense heritability were high for all the traits assessed. The character of the yield per plant, fruit weight and fruit diameter shows that there were more dominant genes in the parents. There were more recessive genes in parents for the fruit length character. IPB C7 parent was the most recessive genes containing control characters in the yield per plant. In the new improved varieties of high yielding, IPB C7 could be crossed with IPB C9. Employing individual or mass selection breeding should be successful in developing high-productivity lines in this population.

Key words: pepper, additive effects, dominant effects, yield component, full diallel

INTRODUCTION

Pepper is one of the important commodities and vegetables with high economic values in Indonesia. This plant is well developed in the lowlands and highlands. According to Badan Pusat Statistik (2009), the national productivity of pepper in Indonesia in 2008 was 6.44 tons per hectare which are much lower than its potential production. According to Purwati *et al*. (2000), the potential productivity can reach 12 tons per hectare.

To meet the increasing demand, various efforts in improving the productivity are very needed. Seed quality of superior varieties is one of the factors influencing the success of agricultural production, including pepper. One effort to improve pepper production and quality is through a breeding program. The program is aimed at the use of superior varieties with high yields and good qualities that can be accepted by farmers (Kusandriani & Permadi 1996).

Before setting the breeding and selection methods we need to correct the character of genetic information. One way to obtain genetic information is the diallel cross analysis. According to Johnson (1963), this method is experimentally a systematic approach, and analytically a comprehensive genetic evaluation approach that is useful in identifying potential cross for the best selection in early generations.

Diallel analysis is useful in intersecting the suspect of the general combining ability (GCA) and the specific combining ability (SCA). This analysis is also useful to predict additive and dominant effects of a population which can then be used to predict the genetic variability and heritability. The combining ability analysis can be conducted using the Griffing Method (Griffing 1956), whereas to study the action of genes, genetic components and heritability can use the Hayman Method (Hayman 1954). Griffing and Hayman data analysis are often used together for complementary data interpretation. The analysis (either one or both) has been used for various plants such as pepper (Sousa & Maluf 2003; Geleta *et al*. 2006; Sujiprihati *et al*. 2007; do Rego *et al*. 2009; Kamble *et al*. 2009; Perez *et al*. 2009; Daryanto *et al*. 2010), wheat (Singh *et al*. 2003), barley (Kakani *et al*. 2007), peanut (Novita *et al*. 2007), papaya (Hafsah *et al*. 2007), and peas (Kalia & Sood 2009).

In hot pepper (*Capsicum chinense* Jacq.), non-additive genetic effects were larger than additive effects for total yield, fruit length/diameter ratio, fruit dry-matter per plant, capsaicin yield per plant and number of seeds per fruit (Sousa & Maluf 2003). Epistasis was detected for fruit dry- matter per plant, capsaicin yield per plant and number of seeds per fruit. Analysis of variance for the combining abilities in chilli pepper (*Capsicum baccatum*) showed that GCA effects exhibited significant differences and SCA effects of the crosses were significant, except for the height

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of first bifurcation. For almost all characters both additive and non-additive effects influenced the performance of hybrids (do Rego *et al*. 2009). The variances due to SCA and GCA in sweet pepper (*Capsicum annuum* L.) showed that the non-additive gene action was predominant though the additive component was also significant (Geleta *et al*. 2006). In previous studies the general combining ability analysis and heterosis of several yield components of pepper (*Capsicum annuum* L.) have been presented. All characters (yield per plant, fruit weight, fruit length, and fruit diameter) are significantly different for heterosis, heterobeltiosis, general and specific combining ability (Sujiprihati *et al*. 2007).

This study was to obtain information about the genetic parameters of yield components of pepper using full diallel analysis of Hayman Method. We analysed the action of genes, genetic components and heritability of the yield components of the pepper.

MATERIALS AND METHODS

Plant Material. The experiment was conducted at IPB Experiment Field, Cikabayan, Darmaga. We used 36 genotypes of six pepper lines (IPB C1, IPB C2, IPB C3, IPB C7, IPB C8, and IPB C9) and 30 hybrids of full diallel crosses among six lines.

Experimental Design. A randomized complete block design (RCBD) was used with three replications, and with 36 genotypes tested there were 108 experimental units. One experimental unit consisted of 18 plants that were planted in beds measuring 1 x 4 m covered with silver black plastic mulch with planting distance of 50 x 50 cm. Seedlings were transferred to the field after the emerging of 4-5 leaf pieces (± 4 weeks old). Fertilizers were applied every week in the form of a solution of 10 g NPK Mutiara and 2 ml Multitonik/liter of water, with a dose of 250 ml/plant. Fertilizer Gandasil D and B (2 g/l) were applied together with the spraying of insecticides and fungicides, each assigned to the vegetative and generative phases.

Observations. Observations were made on samples from 6 plants of each experimental unit. The characters observed were the production per plant (g), fruit weight (g), fruit length (cm), and fruit diameter (mm). Weight, length and diameter of the fruit were observed on the same fruit at the second harvest.

Data Analysis. Data were analyzed using the Hayman approach as followed (Singh & Chaudhary 1979): analysis of variance, variance and covariance estimation, the establishment of the graph Wr-Vr, variance component estimation as well as the other parameters and the most dominant and recessive parents. From the data analysis we obtained: (i) variations due to additive effect (D); (ii) the mean of 'Fr' over the arrays (F), Fr is the covariance of additives and non-additive effects in single array; (iii) components of variation due to the dominance effect of the genes (H_1); (iv) calculations to predict the proportion of positive and negative genes in the parents (H_2); (v) the dominance effects (as the algebraic sum over all loci in heterozygous phase in all crosses) (h^2); (vi) the expected environmental components of variation (E); (vii) the mean degree of dominance ($(H_1/D)^{1/2}$); (viii) the proportion of genes with positive and negative effects in the parents ($H_2/4H_1$); (ix) the proportion of dominant and recessive genes in the parents (Kd/Kr); (x) the number of groups of genes which control the character and exhibit dominance (h^2/H_2); (xi) heritability ini broad sense (h^2_{NS}); (xii) heritability in narrow sense (h^2_{NS}).

RESULTS

There were significantly different for yield per plant, fruit length, weight per fruit and fruit diameter at the level of 1% among genotypes of the pepper (Table 1). The results indicate that the genetic parameter estimates can be performed on all the observed characters.

Gene Interaction. The results of the regression coefficient test b (Wr, Vr) were not significantly different for all observed characters (Table 2), thus no interaction between genes in controlling the yield per plant, fruit length, fruit weight and fruit diameter of the pepper diallel population. These results indicate that one of the assumptions diallel cross analysis could be met.

The Influence of Additive (D) and Dominance (H_1). The influence of additives (D) was significantly different for all the observed characters . The influence of additives to the characters of the yield per plant, fruit length, fruit weight and fruit diameter respectively were 29807, 531, 6501, 10813, and 7902. The influence of the dominant (H_1) was also significantly different for all the observed characters (Table 2).

Gene Distribution in the Parents. Distribution of genes in the parents can be seen from the value of H_2. Only the genes controlling the inheritance of fruit diameter spread evenly in the parents, since the value of H_2 was not significantly different. In the meantime, the genes controlling the inheritance of character yield per plant, fruit length and fruit weight was not spread evenly in the parents, the value of the H_2 indicated significant differences (Table 2).

The proportion of positive genes will be seen from the value of H_1 against H_2. If $H_1 > H_2$ then the genes were more positive genes, on the other hand, if $H_1 < H_2$ then the genes were more negative genes. Genes involved more heavily in determining the character of the yield per plant, fruit length, fruit weight and fruit diameter were positive genes reflected in the value of $H_1 > H_2$ (Table 2).

Table 1. The mean square several yield component of pepper

Source	df	Mean square			
		Yield per plant	Fruit length	Fruit weight	Fruit diameter
Replication	2	10439.73	5.77	15.47	2.17
Genotype	35	64029.34**	19.52**	20.10**	8.34**
Error	70	7899.06	1.22	1.65	0.53

**significantly different at the level of 1%.

Table 2. Estimation of genetic parameters of some yield components of pepper using the diallel analysis of the Hayman Method

Genetic parameters	Yield per plant	Fruit length	Weight fruit	Fruit diameter
Covariance-variance regression (b(Wr, Vr))	0.970ns	0.694ns	0.696ns	1.158ns
Additive effect (D)	29807.531**	12.808**	10.813**	7.902**
Dominance effect (H_1)	25771.346**	3.741**	11.771**	2.693**
Proportion of dominance due to positive and negative effect of genes (H_2)	18901.899**	2.403**	6.412**	1.431ns
F_r mean (F)	5097.550**	-0.965ns	5.689**	3.879**
F1 deviation from the average parent (h^2)	4328.372**	0.232ns	-0.352ns	0.160ns
Environment (E)	2656.544**	0.250ns	0.679ns	0.193ns
Mean degree of dominance ($(H_1/D)^{1/2}$)	0.930	0.540	1.043	0.584
Proportion of dominance genes to recessive genes (H_2/H_1)	0.183	0.161	0.136	0.133
The proportion of dominant to recessive genes (Kd/Kr)	1.203	0.870	1.674	2.451
Number of groups of genes (h^2/H_2)	0.229	0.097	-0.055	0.112
Coefficient of correlation (r) between $W_r + V_r$ and Y_r	0.607	0.606	0.914	0.320
Broad-sense heritability (h^2_{BS})	0.885	0.970	0.910	0.939
Narrow-sense heritability (h^2_{NS})	0.681	0.899	0.697	0.827

** = significantly different at the level of 1%, ns = not significantly different

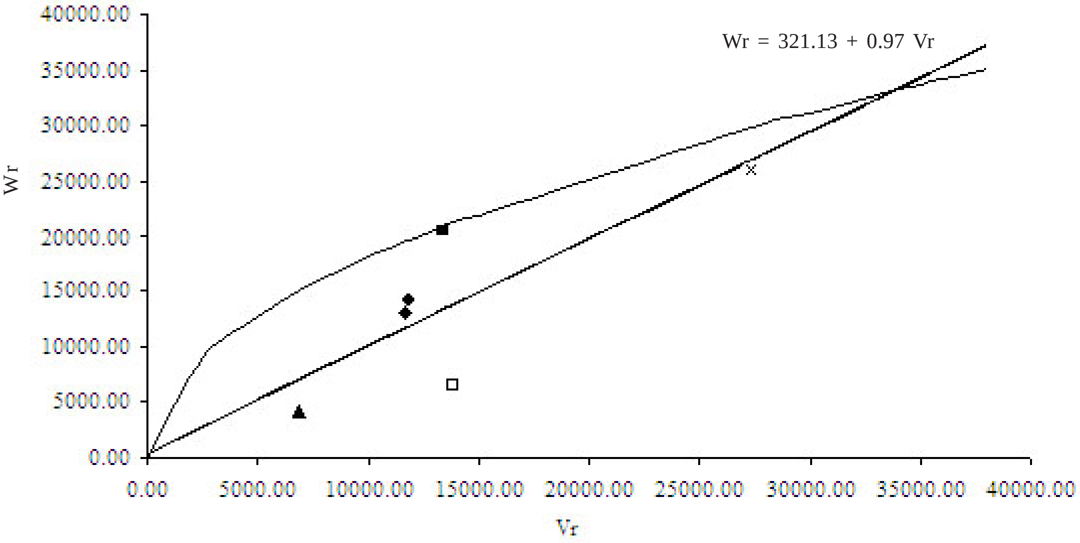

Figure 1. Relationship covariance (Wr) and variance (Vr) of yield per plant character of pepper. (—◆—) IPB C1, (—◆—) IPB C2, (—▲—) IPB C3, (–×–) IPB C7, (—□—) IPB C8, (—■—) IPB C9.

Dominance Level. The amount of dominance effects can be seen from the value $(H_1/D)^{1/2}$. The value $(H_1/D)^{1/2}$ of the yield per plant, fruit length and fruit diameter was less than one indicating a partial recessive, while the value of $(H_1/D)^{1/2}$ on the character of the fruit weight was more than one indicating over-dominance (Table 2).

Proportion of Dominant to Recessive Genes. Table 2 shows that the character of the yield per plant, fruit weight and diameter of the fruit has a value of Kd/Kr > 1 (respectively 1203, 1674, and 2451), showing that the genes were more dominant in the parents. Meanwhile, the length of the fruit character has a value Kd/Kr < 1 (0870), showing that the recessive genes were more in the parents.

Direction and Order of Dominance. The order of dominance of parents to yield per plant was IPB C3, IPB C8, IPB C2, IPB C1, IPB C9, and IPB C7 (Table 3). IPB C7 parent was the most recessive genes containing control characters in the yield per plant, because the most distant from ground zero. In the meantime, IPB C3 contained the most dominant gene, because the closest to zero. The regression line on the graph Wr - Vr has a value of intercept a = 321.13, thus cutting Wr axis above the origin (0). Cutting points in these positions indicates that there was a partially dominant gene action (Figure 1).

Table 3. Distribution Vr + Wr

Genotype	Yield per plant	Fruit length	Weight fruit	Fruit diameter
IPB C1	26015.925	11.056	7.555	3.439
IPB C2	24791.195	12.283	10.417	5.157
IPB C3	11028.152	13.436	9.071	2.368
IPB C7	53484.966	13.774	6.469	7.139
IPB C8	20264.215	7.944	5.225	5.023
IPB C9	33868.256	8.779	13.569	5.708

The order of dominance of parent for the fruit length was IPB C8, IPB C9, IPB C1, IPB C2, IPB C3, and IPB C7 (Table 3). IPB C7 parent was the most widely contain a recessive gene, meanwhile, IPB C8 contained the most dominant genes. The regression line on the graph of Wr - Vr has a value of intercept a = 3.55, so cut the Wr axis above the origin (0). Cutting point at that position indicates a partially dominant gene action (Figure 2).

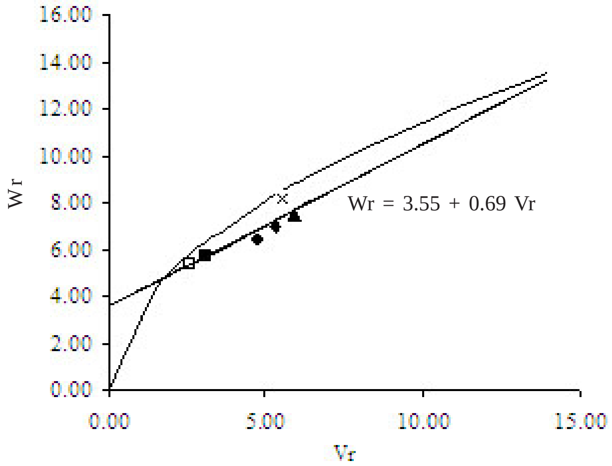

Figure 2. Relationship covariance (Wr) and variance (Vr) of fruit length character of pepper. (—◆—) IPB C1, (—◆—) IPB C2, (—▲—) IPB C3, (–x–) IPB C7, (—□—) IPB C8, (—■—) IPB C9.

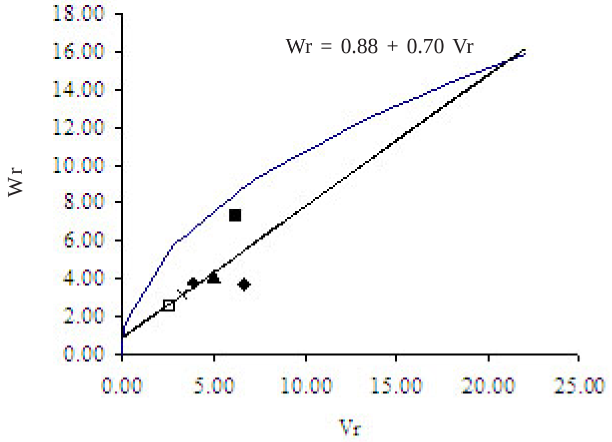

Figure 3. Relationship covariance (Wr) and variance (Vr) of fruit weight character of pepper. (—◆—) IPB C1, (—◆—) IPB C2, (—▲—) IPB C3, (–x–) IPB C7, (—□—) IPB C8, (—■—) IPB C9.

The order of dominance of parents to the weight of fruit was IPB C8, IPB C7, IPB C1, IPB C3, IPB C2, and IPB C9 (Table 3). IPB C9 parent was the most widely contain a recessive gene, meanwhile, IPB C8 contained the most dominant genes. The regression line on the graph of Wr - Vr has a value of intercept a = 0.88, thus cutting the Wr axis above the origin (0). Cutting point at that position indicates a partially dominant gene action (Figure 3).

The order of dominance of parents to the diameter of the fruit was IPB C3, IPB C1, IPB C8, IPB C2, IPB C9, and IPB C7 (Table 3). IPB C7 parent was the most widely contain a recessive gene meanwhile, IPB C3 gene contained the most dominant. The regression line on the graph of Wr - Vr has a value of intercept a = 0.94, thus cutting the Wr axis above the origin (0). Cutting point at that position indicates a partially dominant gene action (Figure 4).

Number of Genes Controlling Characters. Characters, such as: yield per plant, fruit length, fruit weight and fruit diameter were controlled by the recessive genes.

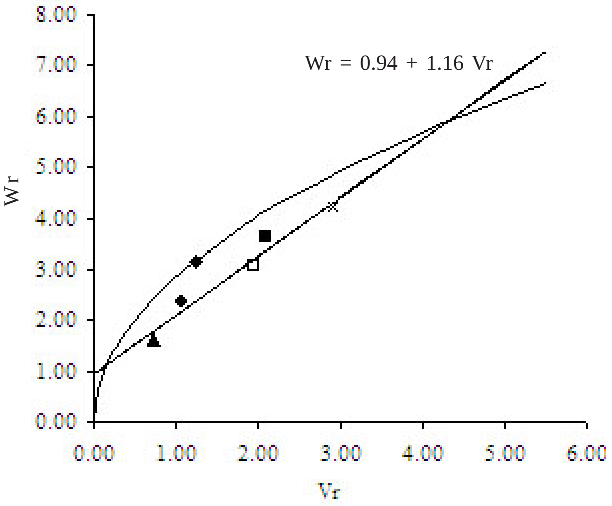

Figure 4. Relationship covariance (Wr) and variance (Vr) of fruit diameter character of pepper. (—◆—) IPB C1, (—◆—) IPB C2, (—▲—) IPB C3, (–x–) IPB C7, (—□—) IPB C8, (—■—) IPB C9.

The degree of controlling genes was reflected in the value h^2/H_2. The number of genes that control the characters of the yield per plant, fruit length, fruit weight and fruit diameter, respectively, was controlled by a group of genes (Table 2).

Heritability. Estimated value of broad sense heritability (h^2_{NS}) for the characters of the yield per plant, fruit length, fruit weight and fruit diameter of including in the high category were 0.885, 0.970, 0.910, and 0.939, respectively. The estimated value of narrow sense heritability (h^2_{NS}) for the four characters were also high, namely 0.681, 0.899, 0.697, and 0.827, respectively (Table 2).

DISCUSSION

Estimation of genetic parameters using cross diallel analysis can be carried out if there are significant differences among genotypes based on the F test of the observed variables (Singh & Chaudhary 1979). Gene interactions can be seen from the value of b (Wr, Vr). If the value is significantly different from the one then there is an interaction among genes; on the other hand, if the value of b is not significantly different from one then there is no interaction among genes (Singh & Chaudhary 1979; Sousa & Maluf 2003). In this study, the value of b was not significantly different from one for all observed traits. Thus, there was no interaction among genes in controlling the characters. Sousa and Maluf (2003) also found that there was no interaction among genes for the total fruit yield of *C. chinense* Jacq. pepper.

The number of dominant genes in the parents is reflected in the value of Kd/Kr. If the Kd/Kr > 1 then there are more dominant genes in the parents. Conversely, if the Kd/Kr < 1 then there are more recessive genes in the parents (Singh & Chaudhary 1979). In this research, the characters of the yield per plant, fruit weight and fruit diameter showed more dominant genes in the parents.

There were more recessive genes in parents for the fruit length character. IPB C7 parent was the most recessive genes containing control characters in the yield per plant. According to Sujiprihati *et al.* (2007), IPB C7 had the yield per plant higher than that of IPB C1, IPB C2, IPB C3, IPB C8, and IPB C9. Thus, in improving new varieties with high yield, IPB C7 could be crossed with IPB C9 because the two genotypes were positioned closely each other (on the graph of Wr-Vr), indicating that both had similar recessive genes (Figure 1).

The order of dominance of parents (based on wr + vr) reflected the content of the dominant genes in parents. The smaller the value of wr + vr, the more dominant genes that could control the characters. The order of dominance is also reflected in the relationship of covariance (Wr) and variance (Vr) of image. The more closely to the zero point of the parents of these genes contain the most dominant, whereas farther from the zero point is the parents containing the most widely recessive genes (Singh & Chaudhary 1979; Sudjindro *et al*. 1991; Sousa & Maluf 2003; Novita *et al.* 2007).

The additive effect (D) played a very real impact on all observed characters. If viewed from the cast of both characters, all yield observed components in pepper diallel population were more influenced by additive gene action, except in the weight of fruit. Sousa and Maluf (2003) showed that the characters of pepper species *C. chinense* Jacq. were more influenced by non-additive gene action.

The estimated value of the Narrow-sense heritability (h^2_{NS}) for the characters of the yield per plant, fruit length, fruit weight, fruit diameter and the high category was included. This shows that the proportion of various additives in determining the characters was quite high and according to the previous explanation the additive effect was very significant. This showed that the variance of the character was controlled by genetic factors (Geleta *et al*. 2006). Several studies indicated that the expected pepper value of the broad sense heritability was high on the fruit weight and yield per plant (Sreelathakumary & Rajamony 2004; Lestari *et al*. 2006; Marame *et al*. 2008), length fruit (Manju & Sreelathakumary 2002; Sreelathakumary & Rajamony 2004; Marame *et al*. 2008), and fruit diameter (Manju & Sreelathakumary 2002; Sreelathakumary & Rajamony 2004; Lestari *et al*. 2006). According to Roy (2000), if the estimated value of the heritability is high, the selection is done in the early generations because of the character of a genotype heritage to the offspring. Variance of additives and narrow sense heritability is high in the population studied and character development program this population that can be done through a selection of the individual or mass selection Method.

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