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Parametric Stability Analysis for Yield of Chili Pepper (*Capsicum annuum* L.)

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ABSTRACT

The objective of this study was to identify the stability of seven hybrid chili pepper genotypes that have been developed at Genetics and Plant Breeding Laboratory, Department of Agronomy and Horticulture IPB. The study used eight yield stability analyses and Additive Main Effect Multiplicative Interaction (AMMI) methods. The design was randomized complete block design with three replications as blocks using the genotypes of IPB CH1, IPB CH2, IPB CH3, IPB CH5, IPB CH25, IPB CH28, IPB CH50, and five commercial varieties, i.e. Adipati, Biola, Gada, Hot Beauty and Imperial. These genotypes were planted at six different locations at Ciherang, Leuwikopo, Tajur, Subang, Rembang and Boyolali. IPB CH28, IPB CH25, IPB CH1 and IPB CH2 were more stable cultivars than IPB CH3, IPB CH5, IPB CH50, Adipati and Biola, which had 10, 9, 8, and 6 out of all 10 stability statistics used, respectively. IPB CH28 and IPB CH25 being the most stable cultivars. IPB CH3 was the best genotype compared to the checks based on pair wise GxE interaction test. Based on post predictive success, the AMMI2 model was able to explain 85.51% of the interaction-influenced variation. The stable genotypes in six locations were IPB CH1, IPB CH2, IPB CH25, IPB CH28, and IPB CH50. IPB CH3 genotype was locally adapted for Subang.

Keywords: chili pepper, multi location trials, yield stability

INTRODUCTION

In 2008, Indonesian national production of chili pepper was 6.44 ton ha^{-1} (Central Bureau of Statistics, 2009). This number is still far below the productivity of chili pepper which may reach 20-30 ton ha^{-1} (Pitojo, 2003). This low productivity may be due to inadaptability of variety used by the farmers. The yield stability analysis can describe the response-pattern of genotype to the environmental changes, thus can be beneficial for the farmers.

Stability analysis had been widely utilized by researchers in order to assist the breeders in analyzing the genotype x environment interaction (GE), yield stability and the interaction between yield stability and environment. These analyses were previously presented by Yates and Cochran (1938), and were continuously studied by other researchers i.e. Finlay and Wilkinson (1963), Eberhart and Russell (1966), and Perkins and Jinks (1968). Crossa (1990) and Flores *et al*. (1998), stated that the genotype stability was measured by three parameters i.e. mean yield, regression coefficient (b_i), and deviation of regression (S^2_{di}). Lin *et al*. (1986) stated that the methods of two parameters proposed by the Eberhart and Russell (1966) were similar to the Tai method (Tai, 1971). In this method, genotype to the environmental effects (α_i) and deviation from the linear response (λ_i) can be developed into a specific form (b_i) and (S^2_{di}), assuming that the environmental index is random.

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The stability analysis using GE for each genotype termed as *ecovalence* (W^2_i) was proposed by Wricke (1962). Furthermore, Shukla (1972) developed the stability method which is known as the Shukla stability variance (δ^2_i). Francis and Kannenberg (1978) used environmental variance (S^2_i) and coefficient of variance (CV_i) as a stability parameter. Other method that can further describe the GE is Additive Main effect and Multiplicative Interaction (AMMI). AMMI is the analysis which combines the additive main effect and multiplication effect in the main component analysis (Mattjik, 2005).

The objectives of this study were (i) to evaluate the yield of several hybrids chili pepper genotypes in several environments, (ii) to describe the GE of several hybrid chili pepper genotypes for yield characteristics, (iii) to study the adaptability of several hybrid chili pepper genotypes using 10 parameters of stability, and (iv) to estimate the correlation level among stability and yield.

MATERIALS AND METHODS

This study was conducted at Ciherang, Tajur and Leuwikopo (Bogor District, West Java, ± 190 m asl), Subang (Subang District, West Java, ± 47 m asl), Rembang (Rembang District, Central Java, ± 47 m asl), and Boyolali (Boyolali District, Central Java, ± 104 m asl). The research was conducted from November 2006 to May 2007 (at Ciherang, Leuwikopo, and Tajur) and from December 2007 to June 2008 (at Subang, Rembang, and Boyolali).

The materials used were 12 genotypes including seven genotypes of IPB's hybrid chili pepper genotypes i.e. IPB CH1, IPB CH2, IPB CH3, IPB CH5, IPB CH25, IPB CH28, IPB CH50 and five commercial varieties i.e. Adipati, Gada, Biola, Hot Beauty and Imperial.

The experiment was arranged in a randomized complete block design with two factors and three replications nested in locations. Each experimental unit consisted of 20 plants. The cultural practice used in these locations was a standard technique for chili pepper. A combined analysis of variance was performed across six locations, to study the genotype influence, environment effects and GE. Barlett's test for the analysis of variance was performed before conducting combined analysis (Gomez and Gomez, 1985). The combined analysis of variance for several locations followed Annicchiarico (2002). Eight stability analysis were used in this study, i.e. the Wricke method (1962), Finlay and Wilkinson (1963), Eberhart and Russel (1966), Perkins and Jinks (1968), Tai (1971), Shukla (1972), Francis and Kannenberg (1972), Lin and Binns (1988), and AMMI stability (Mattjik, 2005). All statistical analyses were carried out using SAS 9.0 program (Hussein *et al.,* 2000).

Wricke (1962) suggested using a genotype environment interaction (GE) for each genotype as a stability measure, and termed as ecovalence (W_i^2). Ecovalence (W_i^2) is a stability value genotype that is square of genotype environment interaction and it is added at all environments. Based on this model, a genotype with a small ecovalence (W_i^2) value is considered as a stable genotype.

Based on the Finlay and Wilkinson stability method, the regression coefficient (b_i = 1.0) is stated as the stability standard. An increment of regression coefficient value (b_i > 1.0) indicates a decrease in the plants' adaptability toward the environment, while a decrement of regression coefficient value (b_i < 1.0) indicates an increase in the plants' adaptability toward the environment.

Eberhart and Russell (1966) had combined the value of regression coefficient (b_i = 1.0) and the value of deviation from regression (S^2_{di} = 0.0) as the mean stability parameter of a genotype. When the parameter is related to a high yield value, the genotype has a wide adaptability, while when it is related to a low yield value, the genotype has a narrow adaptability. A regression value which is more than 1.0 describes a genotype with a high sensitivity toward environmental changes, thus it is only suitable in an optimal environment. A regression value which is less than 1.0 describes susceptibility toward environmental changes and high suitability in a less optimal environment.

According to the Perkins and Jinks stability method, a genotype is stated as very stable if the value of β_i is 0.0 which means the genotype will not be influenced by environmental changes. A genotype with β_i > 0.0 is sensitive toward environmental changes thus suitable in an optimal environment. A genotype with β_i < 0.0 or negative has a few response differences toward the environment and is suitable to be planted in various environments.

The principles of the Tai stability method (1971) is the structural relation analysis where the GE in a genotype consisting of two components i.e. linear response from environmental influence (α) and deviation from linear response (λ). Parameters α = -1 and λ = 1 describe the most stable genotype (not influenced by the environmental changes), while parameters α = 0 and λ = 1 describe the genotype with an average stability.

Shukla used a stability variance (σ^2_i) of genotypes as a stability parameter. Based on this model, a stable genotype is a genotype with an equal stability variance (σ^2_i) to environment variance (σ^2_e); or with a stability variance (σ^2_i) = 0. A high stability variance (σ^2_i) value indicates an unstable genotype. Because the stability variance (σ^2_i) is the difference among two sum square, it can have a negative value (stability variance (σ^2_i) < 0)), estimation value can be considered as a stability variance (σ^2_i) = 0.

According to the Francis and Kannenberg stability method, a genotype is considered to be stable if it shows a low value in genotypic variance (S^2_i) and the coefficient of variability (CV_i). Lin and Binns proposed a stability parameter known as a cultivar performance superiority measure (P_i) that uses the ranges of mean square genotype and its maximum response. A lower P_i value indicates a closer maximum response of a genotype, which implies the best and the most stable hybrid.

RESULTS AND DISCUSSION

Based on the Barlett's test, the data obtained were homogenous for all locations (p = 0.41), therefore, the data analysis was continued to combine variance analysis. The combined analysis showed that genotypes, location and GE significantly influenced the yields. Mean square of locations, genotypes and GE contributes 83.5, 8.33, and 8.16%, respectively (Table 1). It indicated that locations contributed more for yield variance than genotypes and GE.

The mean yield of 12 chili pepper hybrids in six locations ranged from 190.91 g plant^{-1} (Tajur) to 796.41 g plant^{-1} (Rembang), with 26.22% coefficient of variance. In general, IPB CH3 showed the highest mean value for chili pepper yield (555.51 g plant^{-1}) compared to other hybrids at all locations, followed by IPB CH50 (436.88 g plant^{-1}) and IPB CH25 (430.65 g plant^{-1}). IPB CH5 showed the lowest mean value for chili pepper yield (256.64 g plant^{-1}). The lowest mean yield at Tajur was likely due to the severe infection of *Pseudomonas solanacearum* (bacterial wilt) and *Colletotrichum capsici* (anthracnose). In this location, IPB CH1 hybrid produced the highest mean yield (343.71 g plant^{-1}), while the lowest yield was shown by Biola (81.07 g plant^{-1}) and IPB CH5 (62.15 g plant^{-1}). The highest mean yield was obtained from Rembang, since Rembang was a new planting location for chili pepper and had good irrigation. In this location, IPB CH3 produced the highest yield with mean value of 1,113.53 g plant^{-1} (Table 2).

The analysis of 10 stability parameters from 8 methods of stability and yield were shown in Table 3. Based on Perkins and Jinks stability method, IPB CH28 was the best hybrid chili pepper (β_i = -0.003) and high yield

Table 1. Analysis of variance for yield of 12 chili pepper hybrids at six locations

Source of variation	df	SS	MS	$F_{calculated}$	Contribution (%)	Barlett test
Environment (E)	5	4150.013	830.003	200.16**	83.51	0.41ns
Rep./ Location	12	211.994	17.666	4.26**		
Genotype (G)	11	414.184	37.653	9.08**	8.33	
Interaction (GxE)	55	405.544	7.374	1.78**	8.16	
Error	132	547.356	4.147			
Total	215	5.729.091				

Note: ** = significantly different (P < 0.01); ns = homogeneity of variance; Rep. = Replication; df = degree of freedom; SS = Sum of Squares; MS = Mean Square

Table 2. The mean yield (g plant^{-1}) of seven hybrids and five check varieties at six locations

Genotype	Location						
	Ciherang	Tajur	Leuwikopo	Subang	Rembang	Boyolali	Mean
Hybrids							
IPB CH1	234.52ab	343.71a	301.59b	592.10b	751.84bc	260.97bcdef	414.12bc
IPB CH2	200.48ab	200.16abc	190.98bc	488.00bc	846.33ab	309.37bcde	372.44bc
IPB CH3	278.57a	218.69abc	418.41a	827.70a	1113.53a	476.17a	555.51a
IPB CH5	158.24b	62.15c	249.91bc	348.07c	450.97c	270.50bcdef	256.64d
IPB CH25	267.15a	258.64ab	253.64bc	644.61ab	777.67abc	382.20b	430.65b
IPB CH28	213.11ab	218.53abc	276.03b	673.57ab	775.22abc	351.93bc	418.07bc
IPB CH50	276.83a	192.43abc	264.39b	497.53bc	1062.27ab	327.83bcd	436.88b
Check varieties							
Adipati	257.13a	153.41bc	260.67b	448.17bc	730.17bc	216.50ef	344.44c
Biola	243.87a	81.07c	187.88bc	629.37ab	755.83bc	195.00f	348.84c
Gada	240.84a	190.34abc	297.69b	533.33bc	742.62bc	247.03def	375.31bc
Hot beauty	244.13a	216.22abc	135.72c	571.23bc	801.17ab	206.67f	362.52bc
Imperial	211.91b	155.49bc	208.59bc	525.83bc	748.74bc	213.67ef	344.04c
Mean	235.56	190.90	253.74	564.96	796.41	288.15	388.29

Note: Numbers followed by the same letter in the same columns are not significantly different based on DMRT at level α = 5%

(418.07 g plant^{-1}), followed by IPB CH25 (β_i = -0.073) with a yield of 430.65 g plant^{-1}. Even though IPB CH3 has the highest yield (555.51 g plant^{-1}), its β_i value was positive (0.426). Therefore this genotype was only suitable for an optimal environmental condition. Imperial was the best test hybrid because its β_i value was -0.008 and its yield value were close to IPB CH28.

The Finlay and Wilkinson (1963) parametric stability method had shown that IPB CH28, IPB CH25 and the check hybrid Imperial were more stable hybrid. IPB CH5 was the most adaptable genotype to environmental changes but has the lowest yield (256.64 g plant^{-1}). Based on Eberhart and Russell (1966) method, IPB CH28 seems to be a stable hybrid with a wide adaptability, as its value of b_i = 0.997 and S^2_{di} = -267.06, therefore it can be planted in various environment. While IPB CH3 hybrid was only suitable in an optimal environment since the value of b_i = 1.426 and S^2_{di} = 187.86 (Table 3).

IPB CH25, IPB CH28, and IPB CH1 hybrids were among the best hybrids because those cultivars showed low values in genotypic variance (S^2_i) and coefficient of variability (CV_i) as compared to the mean value of genotypic variance (S^2_i = 63271.63) and the coefficient of variability (CV_i = 63.43). Moreover, these hybrids' yield values reach 388.29 g plant^{-1} exceeding the mean value for the yield. IPB CH5 was categorized as a stable hybrid, however, since its yield (256.64 g plant^{-1}) was lower than the mean yield accross cultivars, it was not included among the best hybrids (Table 3).

According to Tai method, IPB CH28 and IPB CH1 were stable hybrids and had yield above average, while Hot Beauty and Biola were stable commercial hybrids. Based on Shukla and Wricke parameters, almost all tested hybrids were proved to be stable, as their stability parameter values were below the mean value, except IPB CH3, IPB CH5, and IPB CH50 hybrids. Referring to the value of grain yield, the best and stable hybrids were IPB CH25, IPB CH28, and IPB CH1, while Imperial was the most stable check hybrid compared to others, for its lowest stability parameter value. Based on Lin and Binns parameter, IPB CH3 was the best hybrid because of its lowest P_i value (P_i = 1302.43) with the highest yield (Table 3).

Genotypic stability is defined-following this condition: a genotype which had higher or equal mean yield than grand mean yield as a precondition was considered to have a stable yield if it appeared stable in more than five out of ten stability analyses. Genotypes that proved to be stable for more than half stability analyses were then selected as promising ones (Akcura *et al.*, 2006; Yasmin, 2007). IPB CH28, IPB CH25, IPB CH1, IPB CH2, Gada, Hot Beauty and Imperial genotypes were more stable cultivars than IPB CH3, IPB CH5, IPB CH50, Adipati and Biola, which had 10, 9, 8, and 6 out of all 10 stability statistics used, respectively. Among these cultivars, IPB CH28 and IPB CH25 were the most stable genotypes, because both had 10 and 9 out of 10 stability statistics used, respectively.

Based on the observation of 10 stability parameters, there are parameters which give similar conclusion, therefore the Spearman correlation analysis needed to be performed in order to determine the relationship level among stability parameters and yield. The result of the Spearman analysis showed that Tai's (1971) stability parameter α_i had a significant positive correlation to yield (α_i = 0.55*), which means the greater α_i value, the greater yield. The Lin and Binns (1988) stability parameter P_i showed significantly negative correlation to yield (P_i = -0.99**), which means the smaller P_i value, the greater yield of a hybrid. The stability parameters of β_i, b_i, and S^2_i were significantly correlated to each other (β_i, b_i, and S^2_i = 1.00**). The stability parameter σ^2_i was significantly correlated to W^2_i ($\sigma^2_i = W^2_i$ = 1.00**). S^2_{di} was also significantly correlated to λ_i ($S^2_{di} = \lambda_i$ = 0.99**) (Table 4).

Several studies indicated that rank correlations among these measures of stability were high (Pham and Kang, 1988; Akcura *et al.*, 2006; Taiwo, 2007; Fikere *et al*., 2009). These facts demonstrated that they measured similar aspects of stability and enables us to use one of these parameters (Akcura *et al.*, 2006). It can also be seen from the rank of each stability parameter (Table 5). The selection response of hybrid chili pepper among stability parameters using the rank system is similar to the Spearman correlation.

IPB CH3 had a significant probability of yield differences (211.07 g plant^{-1}) compared to all check hybrids, followed by IPB CH50 (88.04 g plant^{-1}), while IPB CH5 had the lowest significant of yield difference (-105.88 g plant^{-1}) (Table 6). Based on the Lin and Binns (1985) to calculate yield difference, IPB CH3 was the best tested hybrid because of its greater yield different compared to commercial hybrids. According to Syukur et al. (2010), IPB CH3 has higher productivity than check varieties.

The biplot AMMI2 as a visualization tool of AMMI analysis could be used to determine stable genotypes in all environmental conditions or in certain specific environment. A genotype is stable, if it is located closer to the main axis, while a specific environment genotype is located further from the main axis but closer to the environmental axis (Mattjik, 2005). Based on the post predictive success, the model AMMI2 was suitable since this model was able to explain the interaction-influenced variation as much as 85.51%. Stable hybrids in six environments were IPB CH1, IPB CH2, IPB CH25, IPB CH28, and IPB CH50. Genotype IPB CH3 was specific for Subang, while IPB CH5 was specific for Leuwikopo (Figure 1).

Table 3. Yield stability of 12 chili pepper genotypes at six locations

Genotype	Yield (g plant^{-1})	βi	b_i	S^2_{di}	S^2_i	CV_i	α_i	λ_i	σ^2_i	W^2_i	P_i	F
IPB CH1	**414.12**	-0.163	0.837	893.55	**43,813.88**	**50.55**	**-0.167**	**1.088**	**5,409.01**	**25,097.24**	**20,685.39**	**8**
IPB CH2	372.44	**0.058**	**1.058**	-523.67	66,865.69	69.43	**0.059**	0.739	**2432.88**	**12697.24**	**24,445.48**	**6**
IPB CH3	**555.51**	0.426	1.426	**187.86**	120,142.83	**62.40**	0.435	**0.848**	15442.66	66904.67	**1,302.43**	5
IPB CH5	256.64	-0.485	0.515	908.32	**18,773.71**	**53.39**	-0.496	**1.009**	19849.92	85268.24	69,457.36	3
IPB CH25	**430.65**	**-0.073**	**0.927**	-1,254.82	**51,240.51**	**52.56**	**-0.075**	0.554	**1871.65**	**10358.80**	**15,806.11**	**9**
IPB CH28	**418.07**	**-0.003**	**0.997**	**-267.06**	**59,841.77**	**58.51**	**-0.003**	0.805	**2447.10**	**12756.52**	**16,156.04**	**10**
IPB CH50	**436.88**	0.293	1.294	6,451.53	104,359.65	73.94	0.300	2.468	14853.32	64449.08	**15,020.75**	2
Adipati	344.44	-0.129	0.871	-1,281.14	**45,501.45**	**61.93**	**-0.132**	0.542	**2617.82**	**13467.85**	34,961.22	5
Biola	348.84	0.116	1.116	976.41	75,326.24	78.68	**0.119**	**1.114**	**4570.13**	**21602.48**	30,805.26	4
Gada	375.31	-0.104	**0.896**	-2,604.51	**46,932.09**	**57.72**	**-0.107**	0.211	**953.13**	**6534.15**	26,354.23	**6**
Hot beauty	362.52	**0.072**	**1.072**	510.15	69,424.44	72.68	**0.079**	**0.999**	**3552.30**	**17361.49**	27,777.68	**6**
Imperial	344.04	**-0.008**	**0.992**	-3,096.06	**57,037.29**	69.42	**-0.008**	0.091	**-265.21**	**1455.19**	31,415.96	**6**
Mean	388.29	0.000	1.000	75.02	63,271.63	63.43	0.000	1.000	6144.56	28162.75	26,182.33	5.5

Note: the bold number indicated stable hybrids; the hybrids with a stability frequency of 10 is predicted as the most stable genotype

Table 4. Spearman correlation between 10 stability parameters and yield

Parameters	Yield	β_i	b_i	S^2_{di}	S^2_i	CV	α_i	λ_i	σ^2_i	W^2_i	P_i
β_i	0.49	--									
b_i	0.49	1.00**	--								
S^2_{di}	0.17	0.31	0.31	--							
S^2_i	0.49	1.00**	1.00**	0.31	--						
CV	-0.08	0.78**	0.78**	0.29	0.78**	--					
α_i	0.55*	0.85**	0.85**	0.17	0.85**	0.59**	--				
λ_i	0.22	0.32	0.32	0.99**	0.32	0.28	0.18	--			
σ^2_i	0.13	0.15	0.15	0.84**	0.15	0.07	0.05	0.82**	--		
W^2_i	0.13	0.15	0.15	0.84**	0.15	0.07	0.05	0.82**	1.00**	--	
P_i	-0.99**	-0.54*	-0.54*	-0.17	-0.54*	0.03	-0.55*	-0.22	-0.11	-0.11	--

Note: ** = significant at P < 0.01; * = significant at P < 0.05

Table 5. Stability rank of 12 chili pepper genotypes at six locations

Genotype	Yield	β_i	b_i	S^2_{di}	S^2_i	CV	α_i	λ_i	σ^2_i	W^2_i	P_i
IPB CH1	5	9	9	9	2	1	2	3	9	9	5
IPB CH2	7	3	3	4	8	9	8	7	4	4	6
IPB CH3	1	11	11	1	12	7	12	5	11	11	1
IPB CH5	12	12	12	6	1	3	1	2	12	12	12
IPB CH25	3	5	5	8	5	2	5	8	3	3	3
IPB CH28	4	1	1	2	7	5	7	6	5	5	4
IPB CH50	2	10	10	12	11	11	11	12	10	10	2
Adipati	10	8	8	9	3	6	3	9	6	6	11
Biola	9	7	7	7	10	12	10	4	8	8	9
Gada	6	6	6	10	4	4	4	10	2	2	7
Hot Beauty	8	4	4	3	9	10	9	1	7	7	8
Imperial	11	2	2	11	6	8	6	11	1	1	10

Table 6. Yield differences between tested hybrids and check hybrids based on the Lin and Binns method (1985)

Genotype	Different 1	Different 2	Different 3	Different 4
IPB CH1	69.68	64.28	38.81	51.60
IPB CH2	28.00	23.61	-2.87	9.92
IPB CH3	211.07**	206.67	180.20	192.99
IPB CH5	-87.80	-92.20	-118.67	-105.88**
IPB CH25	86.21	81.82	55.34	68.13
IPB CH28	73.62	69.23	42.76	55.54
IPB CH50	92.44	88.04*	61.57	74.36

Note: ** = significant at P < 0.01; * = significant at P < 0.05

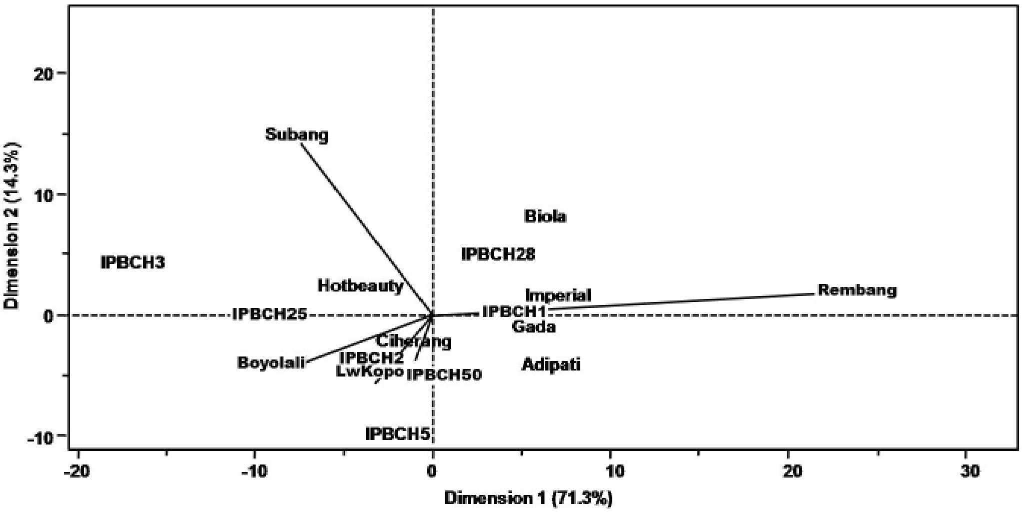

Figure 1. Two-dimensional plot of interaction effect of AMMI2 model for result data of hybrid chili pepper (model suitability 85.51%)

CONCLUSIONS

Based on the yield stability analysis, the stable genotype was IPB CH28, whereas IPB CH3 was the best genotype compared to the checks based on pair wise GxE interaction test. Based on the post predictive success, the model AMMI2 was suitable since this model was able to explain the interaction-influenced variation as much as 85.51%. The genotypes found to be stable in six locations were IPB CH1, IPB CH2, IPB CH25, IPB CH28, and IPB CH50, while IPB CH3 was suitable specifically for the location at Subang only. Some stability parameters have a very significant correlation indicated that they measured similar aspects of stability, thus allowing the use of one parameter among others.

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