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Grain yield stability of maize genotypes grown in paddy fields

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Abstract

Breeding work for identifying the high performance and stable genotypes appropriate for environmental situations in different fields is an important task in maize breeding programs. The objective of this study was to identify high yielding and stable maize hybrids in irrigated paddy fields in the dry season in Thailand. Three new hybrid varieties (Suwan 5720, Suwan 5819 and Suwan 5821) from the National Corn and Sorghum Research Center, and three commercial cultivars (Nakhon Sawan 3, Nakhon Sawan 5, and S 7328) from public and private agencies, were planted and evaluated for grain yield stability in paddy fields in the dry season. Fourteen experimental yield trials were conducted in a randomized complete block design (RCBD) with four replications in Saraburi, Chai Nat, and Phra Nakhon Si Ayutthaya provinces in the dry seasons of 2018-2021. The genotype main effect plus genotype by environment interaction (GGE) model was used to analyze yield stability. The combined analysis of variance showed that the effect of the environment, genotype and genotype-environment interaction (GEI) of grain yield had highly significant differences. The commercial cultivar S7328 (b=0.84) performed the highest grain yield and yield stability, followed by the new hybrid, Suwan 5821(b=0.89), then Nakhon Sawan 5 (b=0.91), Suwan 5720 (b=0.81), and Nakhon Sawan 3 (b=0.97) except Suwan 5819 (b=1.58) had more variation. Based on the GGE model, the biplot explained 76.42% of total variation with PC1 (56.91%) and PC2 (19.51%). S7328 and Suwan 5821 had high yield stability and grain yield, whereas Nakhon Sawan 3 and Nakhon Sawan 5 had the highest grain stability with less grain yield. Therefore, the new hybrid Suwan 5821 could be recommended to farmers for planting in paddy fields during the dry season with irrigation.

Keywords: *dry season; GGE, maize; paddy field; stability; multi-environment trials.*

1. Introduction

Maize (*Zea may* L.) is a potential economic crop of Thailand. Mostly, it is grown in upland areas in the central, north, and northeast regions. Thailand's planting areas in the northern regions are larger than others. The maize growing area in Thailand is estimated at around 1.134 million hectares, with a total maize production of 4.995 million tons and an average yield of 4.405 tons/hectare (Office of Agricultural Economics, 2020). Maize yield production in Thailand has not been enough to supply local demands during the past ten years. The relevant public sector agencies have encouraged farmers to increase more planting areas by utilizing paddy fields during the dry season, after the rice crop has been harvested, to increase grain yields (Office of Agricultural Economics, 2018). In addition, an increase in the grain yield per unit is also necessary. Farmers have often rotated rice crops with maize in the off-season because of the limited water supplies for rice. Maize crop usually uses 40 to 50 % less water than rice crop (Tuong, & Bouman, 2003). However, farmers have to consider using suitable varieties for their specific locations. Maize hybrid varieties are one of the best options in the present. They provide uniformity of plant and high yield for farmers (Macrobert, Setimela, Gethi, & Regasa, 2014). The yield potential of a hybrid variety over an open-pollinated variety is the main component for determining the attraction of maize hybrids. Generally, maize breeders improve crop varieties by focusing on essential traits such as higher yielding, disease and insect resistance, drought tolerance, and fast-maturing that can escape drought (Tester, & Langridge, 2010). Maize hybrid varieties have been used in Thailand since 1980, and currently, they are grown almost 100% in many places. Farmers grew new hybrid varieties as recommended by seed companies and stopped using the old hybrid varieties when their yield was failing. In contrast, the new hybrids that perform well with good adaptability in their locations are used frequently (Poolsawas, & Napasintuwong, 2012). For maize research, Kasetsart University has played the lead role with support from Rockefeller Foundation’s Inter Asian Corn Program in the National Corn and Sorghum Research Center since 1966, and breeders released OP cultivars (Suwan 1, Suwan 2, and Suwan 3). These varieties have been used as the main germplasms in maize improvement projects for both the public and the private sectors (Ekasingh, Gypmantasiri, Thong-ngam, & Grudloyma, 2004). There are many hybrid varieties on the market from private companies and public sector institutes. However, Suwan 5720, Suwan 5819, and Suwan 5821 are elite hybrid varieties, improved by Kasetsart University’s researchers (Jompuk, Jampatong, Boonrumpun, Chaiyasit, & Jompuk, 2019). The yield trials in multi-environments are required to evaluate their stability compared with commercial cultivars on the market before promoting them to farmers (Mushayi, Shimelis, Derera, Shayanowako, & Mathew, 2020). The varieties that showed high yielding stability or wide adaptability could be extended to farmers to plant in their locations. Stable cultivars refer to the cultivars which give stable mean yield in multi-environments or with fewer variations (Eberhart, & Russell, 1966). Commonly, plant breeders always want to develop widely adapted varieties for various environments. However, it is not easy to improve the new ones that are higher in grain yield and retain their components for growing in all locations (Annicchiarico, Bellah, & Chiari, 2015). The phenotype of variety performs by environment effect, genotype effect, and genotype by environment interaction effect (GEI). The widely adaptable cultivars are those that display unchanged or the least changed performance under differing environmental conditions. Evaluating grain yield under multi-environments is one of many approaches to verify the genotype's stability (Kang, 1997; Yan, Hunt, Sheng, & Szlavnics, 2000). Furthermore, many researchers used various methods to analyze the stability of varieties. However, the genotype main effect plus genotype by environment interaction (GGE) method has been widely applied to analyze and interpret GEI, and the results can be displayed graphically. GGE biplot is the primary method to recommend specific genotypes for each group of mega environments by the “which-won-where” pattern. In addition, this method can evaluate the ideal genotypes with high yielding stability and ideal environments with the power of discriminating and representing to select widely adapted genotypes (Yan, Kang, Ma, Woods, & Cornelius, 2007; Mushayi et al., 2020; Sharma, Leskovar, Crosby, & Ibrahim, 2020; Ruswandi et al., 2021; Olanrewaju, Oyatomi, Babalola, & Abberton, 2021; McPherson, 2022).

2. Objectives

This experiment aimed to identify high yielding and stable maize hybrids in irrigated paddy fields in the dry seasons in Thailand.

3. Materials and methods

3.1 Plant materials

This research used six hybrid varieties, including three new varieties, Suwan 5720, Suwan 5821 and Suwan 5819, from the National Corn and Sorghum Research Center, Kasetsart University, Nakhon Sawan 3 and Nakhon Sawan 5 from Nakhon Sawan Field Crop Research Center, and S7328 from the Syngenta Seeds Co., Ltd. (Table 1).

Table 1. The variety, parental lines and source of maize varieties

Entry	Variety	Parental lines	Source
1	Suwan 5720	Ki 61 × Ki 60	National Corn and Sorghum Research Center
2	Suwan 5819	Ki 63 × Ki 60	
3	Suwan 5821	Ki 62 × Ki 60	
4	Nakhon Sawan 3	TF 1 × TF 3	Nakhon Sawan Field Crop Research Center
5	Nakhon Sawan 5	TF 7 × TF 5	
6	S7328	-	Syngenta Seeds Co., Ltd.

- data not available

3.2 Design of the experiment and agricultural practice

A randomized complete block design (RCBD) was applied with four replications in each experiment under fourteen paddy fields in Saraburi, Chai Nat, and Phra Nakhon Si Ayutthaya provinces from 2018 to 2021 (Table 2). In addition, three consecutive yield trials of the six hybrids were conducted during December 2018-April 2019, December 2019-April 2020, and December 2020-April 2021. Each plot size was four rows, 0.75 m apart, 5 m in length, and 0.20 m for the distance between adjacent plants in the row. Two seeds were grown in each mound and thinned to one plant per mound remaining at the 4-leaf stage. The basal N:P:K fertilizer (16:16:16) was applied at approximately 156 kg/ha. Approximately 250 kg/ha of N fertilizer (46:0:0) was added two times at 21 and 50 days after planting with half in each time. Atrazine, a pre-emergence herbicide, was used at the rate of 8 kg/ha. Insecticides and pest disease management were applied as required according to local practices. The experiments were irrigated using a rain pipe irrigation system.

Table 2. List of the fourteen environments of paddy field conditions for growing in 2018 to 2021

Crop year	Environment	Location				Soil type
		Latitude	Longitude	District	Province	
December 2018-April 2019	E1	14°36'49.3"N	100°42'34.5"E	Ban Mo	Saraburi	Clay soil
	E2	14°36'49.9"N	100°42'31.3"E			
	E3	14°22'39.4"N	100°36'05.0"E	Hantra	Phra Nakhon Si Ayutthaya	Clay soil
	E4	14°22'38.4"N	100°36'06.0"E			
	E5	15°09'09.3"N	100°10'57.1"E	Sappaya	Chinat	Silty clay loam
	E6	15°09'06.6"N	100°10'52.4"E			
December 2019-April 2020	E7	14°36'50.2"N	100°42'30.3"E	Ban Mo	Saraburi	Clay soil
	E8	14°36'49.2"N	100°42'34.2"E			
	E9	15°09'06.6"N	100°10'52.4"E	Sappaya	Chinat	Silty clay loam
December 2020-April 2021	E10	14°36'48.1"N	100°42'31.8"E	Ban Mo	Saraburi	Clay soil
	E11	14°36'50.0"N	100°42'34.4"E			
	E12	14°36'49.1"N	100°42'30.3"E			
	E13	15°09'07.6"N	100°10'47.0"E	Sappaya	Chinat	Silty clay loam
	E14	15°09'09.0"N	100°10'49.7"E			

3.3 Data collections and statistical analysis

Data were recorded on some agronomic traits, including male and female flowerings, plant and ear heights, grain moisture content, and grain yield. Male and female flowerings were measured by counting from the date of first giving water to the maize till the date of 50% tasselling and silking flowering in each plot. The average of ten random plants per plot was measured from the ground level to the top node bearing ear for ear height data and to the flag leaf collar for plant height data. The grain moisture content at harvesting was measured using the grain moisture machine (Steinlite, SB 900) and to test sample grains (100 grams per plot). The shelling percentage was determined from five ears randomly sampled after harvesting and using the following formula to calculate (shelling percentage = (grain weight/ear weight) × 100)). The grain yield was harvested from two middle rows per plot and modified to tons per hectare at 15% moisture content. R statistical program was used to calculate the analysis of variance (R Development Core Team, 2021). The GGE model (Yan et al., 2007) and regression coefficient value (b) (Eberhart, & Russell, 1966) considered the stability analysis of grain yield. The biplots were displayed using the R graphical interface of the 'Biometric.KPS' package.

4. Results and discussion

4.1 Combined analysis of variance

Combined analysis of variance on the agronomic traits and grain yield indicated significance at P≤0.01 for the effects of the environment (E) and genotype (G). On the other hand, the genotype × environment (G × E) effects on the grain yield, moisture content, the day to 50% flowering, and the ear height were significant at P≤0.01 whereas, the plant height and the shelling percentage were significant at P≤0.05 (Table 3). This result was consistent with Ye, Chen, Liu, and Yue, (2021) that exhibited the significance for the genotypes × environments effects on the grain yield. Furthermore, all agronomic traits considered were significant for the environment effects (E) and genotype effects (G) (Kpotor et al., 2014).

Table 3 Mean square of combined ANOVA on agronomic traits and grain yield across fourteen environments

Source of variance	Df	Grain yield	Shelling percentage	Male flowering	Female flowering	Plant height	Ear height
Environments (E)	13	18.44**	48.23 **	306.09**	325.6**	4755 **	1869**
Block/E	42	2.37	9.05	1.98	2.0	274	225.2
Genotypes (G)	5	15.06**	122.49**	236.51 **	251.90**	5317**	3307**
G × E	65	2.13**	9.32*	12.29**	12.48**	214*	134**
Error	210	0.84	6.04	1.19	1.26	156	83

* = significant difference at P≤0.05
** = significant difference at P≤0.01

From the combined analysis over fourteen environments, grain yield data showed that S7328 was the highest grain yield variety (8.72 t/ha), followed by Suwan 5821, Suwan 5819, Nakhon Sawan 5, and Suwan 5720 giving grain yield of about 8.34, 8.22, 7.99, and 7.85 t/ha, respectively. In contrast, Nakhon Sawan 3 was the lowest grain yield (Table 4). Moreover, the regression coefficient (b) of all hybrids was not significant from 1 using Eberhart and Russell (1966), except Suwan 5819, meaning that the grain yields of these varieties were stable. Suwan 5819 was the highest shelling percentage (82.95%) and followed by Suwan 5821 (81.96%), while the lowest shelling percentage was S7328 (78.63%). Nakhon Sawan 5 displayed early male (59 d) and female (59 d) flowerings. In contrast, the male and female flowering of the rest of the varieties ranged from 63 to 65 d with the latest flowerings of S7328. Suwan varieties trended to taller than the Nakhon Sawan varieties, while S7328 was in the middle size. The plant height ranged from 199 – 225 cm with an average of 215 cm, while the ear height ranged from 109 – 130 cm, averaging 123 cm (Table 4).

Table 4 Average grain yield, regression coefficient (b), standard deviation of b (sd) and agronomic traits over the fourteen environments growing during 2018-2021

Variety	Grain yield (t/ha)	b$^{1/}$	sd $^{2/}$	Shelling percentage (%)	Male flowering (days)	Female flowering (days)	Plant height (cm)	Ear height (cm)
1. Suwan 5720	7.85 c	0.81	0.227	81.01 c	62 c	63 c	224 a	130 a
2. Suwan 5819	8.22 b	1. 58**	0.197	82.95 a	64 b	65 b	225 a	128 a
3. Suwan 5821	8.34 b	0.89	0.178	81.96 b	62 c	63 c	218 b	122 d
4. Nakhon Sawan 3	7.19 d	0.91	0.159	80.39 c	62 c	63 d	210 c	124 bc
5. Nakhon Sawan 5	7.99 bc	0.91	0.147	80.50 c	59 d	59 e	199 d	109 c
6. S7328	8.72 a	0.84	0.290	78.63 d	65 a	65 a	213 bc	127 ab
Mean	8.05	-	-	80.91	62	63	215	123
F-test	**	-	-	**	**	**	**	**
CV (%)	11.41	-	-	3.04	1.75	1.78	5.82	7.38

Mean with the same letter in each column is not significant.

$^{1/}$ regression coefficient value of grain yield, $^{2/}$ standard deviation of b, **= significant difference at P≤0.01, - = not determine

4.2 Yield stability analysis by GGE method

4.2.1 Environment evaluation

The which-won-where pattern can classify and identify the specific genotypes which performed the best in each group of environments. On the which-won-where GGE biplot, the genotypes placed on the polygon's vertices carried out either the poorest or the best in each group of the environments. The winning genotype position for each environment group is on the vertex of the group. The polygon is divided into sectors by perpendicular lines (Kang, 1997; Yan et al., 2000). In this experiment, GGE biplot described 76.42% of total variation with 56.91% of PC1 and 19.51% of PC2. Furthermore, the polygon was divided into five sectors. The fourteen test environments were separated into three environment groups by which-won-where biplot as group (i) E9; group (ii) E1, E2, E3, E5, E7, E8, E10, E11, and E13; and group (iii) E4, E6, E12, and E14. In addition, Suwan 5720 (1) and Nakhon Sawan 3 (4) positioned on the polygon's vertices in the group (i) indicated that they had the best performances for the environments in this group, followed by Nakhon Sawan 5 (5). Moreover, S7328 (6) and Suwan 5821 (3) had the best performances in the environments within the group (ii). Suwan 5819 (2) was on the vertices of the group (iii), so is expected to be the best genotype for grain yield in the environment of this group (Figure. 1). The percentage of the variation by the GGE model in the experiment was higher than several other research articles, such as Al-Naggar, Shafik, and Musa (2020) explained 67.86% of GGE variation (42.16% of PC1 and 25.70% of PC2), Mitrović et al. (2012) indicated the first two principal components explaining 62.40% of GGE variation (44.34% of PC1 and 18.06% of PC2) and Badu-Apraku et al. (2012) reported that for the grain yield, the PC1 captured 62.1% and PC2 explained 11.4%, the total GGE variation together accounted for 73.5%. Moreover, Olanrewaju et al. (2021) showed that the biplot explained 80% of the total variation observed, of which 48.59% was explained by the first principal component, while the second principal component explained 31.41%. They used the which-won-where pattern to identify the best winners for the mega environment. The environments within the same sector with the varieties that performed the best yield are considered mega environments.

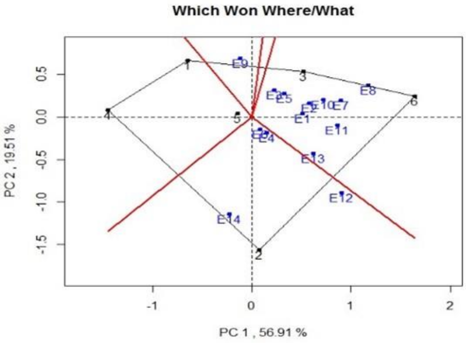


Figure 1 Which won where biplot for the grain yield with six varieties and the fourteen environments.

4.2.2 Ideal genotype evaluation under the paddy field conditions

The ideal genotype contains both high stability and high mean performance across multi-locations. The mean vs. stability biplot (Figure. 2) is used to investigate genotype performance and stability. On the mean vs. stability biplot, ideal genotypes are positioned on the point of the concentric circles. They have a vector at the positive direction on the average environment axis (AEA) (Yan et al., 2000; Yan et al., 2007; Mushayi et al., 2020). The solid horizontal axis represents the average of environments, and the original indicates stability. Each genotype close to the AEA will be more stable. The solid vertical axis indicates the average grain performance of genotypes. In this research, S7328 (6) was identified as an ideal genotype and the most desirable variety, determined by its position on the same side of concentric circles and the farthest from the original biplot. Moreover, the order of hybrids in terms of grain yield performance in descending order was as follows: S7328 (6), Suwan 5821 (3), Suwan 5819 (2), Nakhon Sawan 5 (5), Suwan 5720 (1), and Nakhon Sawan 3 (4). Nakhon Sawan 3 (4) demonstrated the poorest grain yield performance due to its staying on the left side of the solid horizontal axis. Furthermore, a longer variety projection to the AEA line means more variable and less stable across environments. Therefore, grain yield stability in descending order was as follows: Nakhon Sawan 5 (5), Nakhon Sawan 3 (4), S7328 (6), Suwan 5720 (1), and Suwan 5819 (2). The stability of cultivar levels depended on the distances of perpendicular lines from the variety to the AEA axis. The genotypes with shorter distances had higher grain yield stability than the others (Yan et al., 2007; Mushayi et al., 2020). However, the best variety should have a high grain yield and good grain yield stability. Therefore, Suwan 5821 (3) was the best variety from the public sector, comparable to the best one (S7328) from the international company.

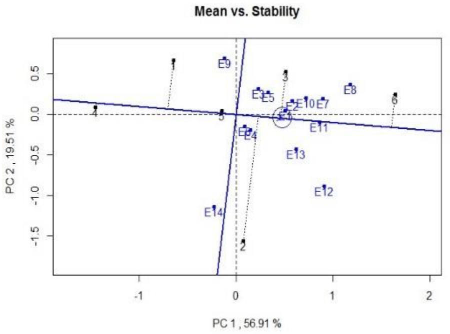
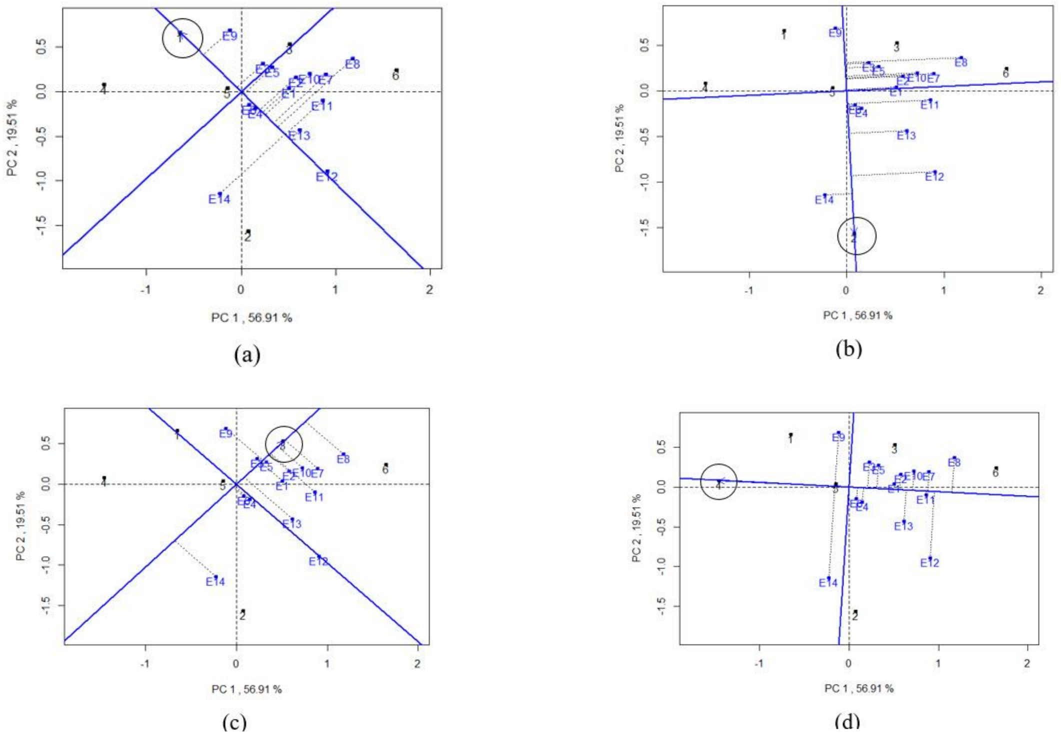


Figure 2 Evaluation of six maize hybrids based on both stability performance and grain yield across the fourteen environments by GGE-biplot method

4.2.3 Ranking the paddy field conditions based on the genotype performance

GGE can be applied to rank the test environments to evaluate the specific adaptability of the genotypes based on their performances in each location. The suitable locations for specific genotypes were positioned in the same direction of that genotype vector and farther from the origin biplot (Yan et al., 2000); Yan et al., 2007; Mushayi et al., 2020). Based on the relative performance of Suwan 5720 (1), it showed higher performance in E9 and E3 (Figure 3a). Suwan 5819 (2) was suitable in E14, E12, E13, E4, E6, and E11 (Figure 3b). Furthermore, Suwan 5821 (3) performed better in all test environments except E4, E6, and E14 (Figure 3c). Nakhon Sawan 3 (4) rated higher yield performance in E9 and E14 (Figure 3d), while Nakhon Sawan 5 (5) showed a good yield only in E9 (Figure 3e). Moreover, the variety with the best grain yield, S7328, was good in all environments except only E14 (Figure 3f).

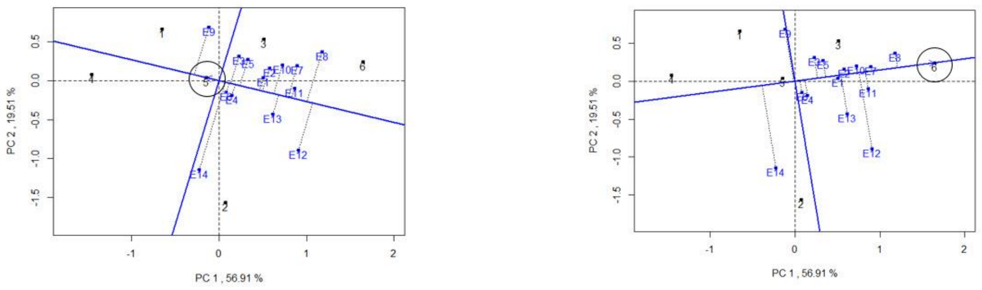


(a)

(b)

(c)

(d)



(e)   (f)

Figure 3 The ranks of the test environments by examining; (a) Suwan 5720 (1), (b) Suwan 5819 (2), (c) Suwan 5821 (3), (d) Nakhon Sawan 3 (4), (e) Nakhon Sawan 5 (5), and (f) S7328 (6)

4.2.4 Ideal test environment

The test environment evaluation was advantageous to classify the effective test locations for selecting the better genotypes for multi-environments. The most representative and discriminating target environment was the main character for the ideal test environment. The discriminative ability of the test environments is described based on the length of the environment vectors. The longer vectors were more highly discriminative by providing more information on the genotype's performance than others (Yan et al., 2000; Yan et al., 2007; Mushayi et al., 2020). The length of Chai Nat (E14 and E13) and Saraburi (E12, E11, E10, E8, and E7) environmental vectors were longer. They are considered the most discriminating environments, whereas the Chai Nat environments (E6 and E5) and Phra Nakhon Si Ayutthaya environments (E3 and E4) with the shortest vectors were the least discriminating (Figure 4). The angles between the test environments with the AEA line identified the representative ability of the test environments. On the GGE biplot, the small circle with the arrow at the end of the vector represented the average environment. The line drawn from the biplot origin to that small circle represents the AEA line. The more representative environment had a smaller angle with the AEA line. The GGE biplot of this study indicated that Saraburi environmental vectors (E11, E1, E2, E7, E10, and E8) made smaller angles with AEA line than others, and are considered to be more representative. On the other hand, the larger angles between Chai Nat (E14, E13, E9, E6, and E5) and Phra Nakhon Si Ayutthaya (E4 and E3) environmental vectors with the AEA line showed they were the least representative (Figure. 4). Based on these results, the Saraburi test environments had high representativeness and discriminating ability, providing more information on genotypes than Chai Nat and Phra Nakhon Si Ayutthaya test environments.

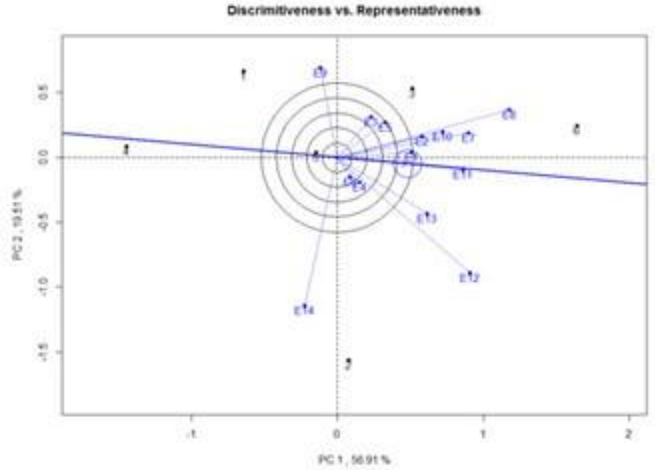


Figure 4 GGE biplot of the representativeness and discriminating ability of the test environments

3.2.5 Ranking test environments relative to the ideal environment and genotype

On the ranking environment biplot, the ideal environment is located in the first concentric circle in GGE biplot. The test environment with a position close to the ideal tested environment was more for the desired environment (Yan et al., 2000). In the GGE biplot, the Saraburi environments (E11, E7, E8, E10, E2, and E1) were the same direction as the ideal test environment vector. Based on this, E11, E7, and E8 were located closer to the ideal test environment and had been ideal environments (Figure. 5). These environments were the places with the best potential for selecting a discriminant genotype, favoring the ideal genotype as S7328 (6) (Figure.3f). Moreover, the environments with the longer vector and larger angle with the AEA axis (E9 and E14) or the shorter vector with the smaller angle (E3, E4, E5, and E6) cannot select superior genotypes (Badu-Apraku et al., 2012). However, the test locations with high discriminating ability but least representative (E9 and E14) were considered the poorest test environments for selecting genotypes with wide adaptability (Figure. 5) (Kumar et al., 2014).

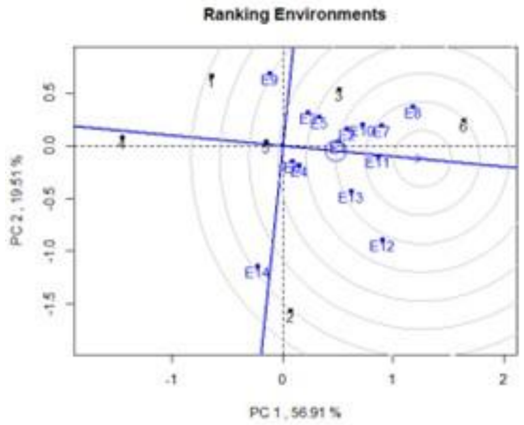


Figure 5 GGE biplot of the rank test environments

5. Conclusion

The results indicated that the environment effect, genotype effect, and the genotype by environment interaction effect were all highly significant on the grain yield. Suwan 5821 was the ideal genotype with high yielding stability in Saraburi, Chai Nat, and Phra Nakhon Si Ayutthaya provinces from 2018 to 2021. The paddy fields in Saraburi environments were more desirable for selecting widely adapted genotypes. Among the new hybrid varieties, Suwan 5821 is a more stable variety compared to the commercial cultivars for planting in the irrigated paddy fields in dry seasons of Thailand after harvesting rice crops. Therefore, farmers should grow maize genotype Suwan 5821 for getting the higher production in their paddy fields in Thailand.

7. Acknowledgements

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