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Stability of oil palm (*Elaeis guineensis* Jacq.) progenies on yield and yield Components across environments using AMMI analysis

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Abstract

Southern Thailand is annually affected by climate change, which impacts on yield performance of oil palm. Therefore, effect of climate change on adaptability, cultivation and yield of oil palm in various planting areas was investigated. This research aimed to evaluate the adaptability of six oil palm progenies (cross numbers 110, 118, 119, 130, 132 and 137) at 5 year-old-plants grown in three environmental areas of southern Thailand: Nakhon Si Thammarat, Phatthalung and Songkhla provinces. The experiment was arranged in a completely randomized design with five replications per treatment (1 tree/replicate) in each environment during 2013-2014. The additive main effects and multiplicative interaction (AMMI) model was used to analyze the stability of yield and yield components. The results showed that the variances attributed to environment (E), genotype (G) and their interactions (G x E) were highly significant. The yield of each progeny depended on growth location. The AMMI biplot analysis showed that progeny 110 was the most stable genotype based on yield and yield components in all the environments. The highest yield of fresh fruit bunches in Phatthalung, Songkhla and Nakhon Si Thammarat provinces were obtained in progeny 130 (403.16 kg/palm/year), progenies 132 and 137 (303.20 and 297.96 kg/palm/year), and progeny 119 (283.52 kg/palm/year), respectively. This indicates that the suitability of an oil palm progeny in general depends on the specific environment for planting.

Keywords: AMMI Biplot, *Elaeis guineensis* Jacq., G x E interaction, stability, yield.
Abbreviations: AMMI_additive main effect and multiplicative interaction; NRT_Nakhon Si Thammarat Province; PCA_principal component analysis; PC_Principal component; PLG_Phatthalung Province; SKA_Songkhla Province.

Introduction

Oil palm (*Elaeis guineensis* Jacq.) is a globally important oil crop species that is widely cultivated in Southeast Asian countries, including Malaysia, Indonesia and Thailand (Wilcove and Koh, 2010). In Thailand, palm oil demand has continuously increased with its uses in foods, feeds and fuels (as alternative energy). Thailand government is promoting biodiesel to reduce the importation of fossil fuels and to strengthen energy security of the country. An Alternative Energy Development Plan (AEDP 2012-2021) has been established with the goal to increase by 25% the national renewable energy consumption by year 2021. Therefore, oil palm plants have been expanded (Sutabutr, 2012). The oil palm plantation has expanded rapidly from 643,840 ha in 2014 to 684,160 ha in 2015 (Office of Agricultural Economics, 2015).
Traditionally, oil palm is cultivated in southern Thailand, but recently this has been expanded to the northern, northeastern and central lowlands. However, limitations to such expansion include unsuitable soil or geography, climatic variability, crop management issues and unadaptable germplasms that ultimately affect growth and productivity (Corley and Tinker, 2003). Therefore, varieties need to be tested for their adaptability and cultivation in various planting areas and also recommendation of appropriate oil palm varieties for specific planting areas. On the other hand, some varieties might have potential for use in diverse environments. These considerations give importance to the genotype by environment (G x E) interactions (Ataga, 1993; 2010).
The G x E interaction is a major concern in plant breeding for two main reasons. Firstly, they can reduce progress rate of selection. Secondly, they make cultivar recommendations difficult because it is statistically impossible to interpret the main effects (Kang and Gauch, 1996). Several statistical methods for estimating the relative stability of performance by genotype across environments such as regression analysis have widely been used, but they have some limitations. Linear regression is oversimplified and potentially misinforms, making it largely irrelevant (Yates and Cochran, 1938; Finlay and Wilkinson, 1963; Eberhart and Russell, 1966). Gauch (1992) proposed the Additive Main effects and Multiplicative Interactions (AMMI) model, which appears more efficient than other statistical methods with multi-environmental yield trials. Using principal component analysis (PCA) the interactions can be further decomposed.
The AMMI model combines analysis of variance (ANOVA) with PCA. The ANOVA is used for considering main effects of genotype and environment and PCA is used for the residual multiplicative interactions of genotype and environment (Zobel et al., 1988; Crossa et al., 1990). AMMI biplot

graphical assessment shows differences in genotype stability and adaptability across the environments, in a scatter plot of genotypes according to their PCA scores (Gauch, 1992). Importantly, the AMMI biplot graph presents the relationship of average traits and PCA1 and shows G x E interactions. The closer that PCA1 is to zero, the more stable the genotypes are across the testing environments. Another graph presents the relationship between PCA1 and PCA2, which indicates the suitability of a variety for any environment. If the plot-point of a variety is closest to one environment, it will be considered suitable for that specific environment (Gauch, 1992). The objectives of this study were to understand the G x E interactions on yield and yield components for six oil palm progenies and to identify progenies that are stable in yield and specific to an environment, using AMMI analysis.

Results

AMMI analysis

Homogeneity of variance tests indicated homogeneous error variance for each trait in the three locations, which allows combined analysis across these locations. The combined analysis of variance indicated significant effects from environment, genotype and G × E interactions on all the traits measured (data not shown). The AMMI analysis showed that the variances attributed to environment, genotype and G × E interactions were highly significant ($P < 0.001$), and in the excepted bunch number the variance by environment was significant ($P< 0.01$) (Table 2). For bunch number, the percentages of sum of squares attributed to environment, genotype and G × E interactions were 7.67, 18.20 and 32.99%, respectively, while the variance in average bunch weight was similarly attributed 37.77, 14.60 and 18.94%, respectively. For fresh fruit bunches yield the contributions were 12.64, 23.00 and 24.46%, respectively. Obviously, the location affected yield and yield components across all the progenies tested.

AMMI Biplot analysis

The AMMI biplot for bunch number was generated by genotype and environment as shown in Fig 3a. The x-axis shows the main effect while the y-axis shows the first PC axis. The results show that progenies 137 and 110, with the PC1 scores relatively close to zero, have less response to the interaction; and therefore, good general adaptation to the test environments. Progeny 137 with average of 25 bunch/palm/year had a positive interaction score (0.12), while progeny 130 had a negative interaction score (-1.14). In addition, the analysis of bunch number shows that PC1 and PC2 accounted for 62.4% and 37.6%, respectively (Fig 3b). Biplot analysis revealed the best genotypes "progeny 130" for the various environments and accurately identified the best genotype for Phatthalung Province (PLG). Progenies 137 and 132 were best for Nakhon Si Thammarat Province (NRT) and Songkhla Province (SKA), respectively.
Fig 4a. shows the PC1 scores vs. average bunch weight, with progenies 118 and 110 having close to zero scores. Progeny 130 had the largest positive interaction score and the highest mean bunch weight at 14.01 kg/bunch and is best adapted for the SKA environment (Fig 4b). The decomposition of variance to PC1 and PC 2 was 79.4% and 20.6%, as shown in Fig. 2b. The biplot revealed the best progeny as 119 for PLG, while progenies 137 and 130 were the best for NRT and SKA, respectively.
Results of fresh fruit bunch yield are presented in Fig 5a. Progeny 110 with PC 1 score closest to zero had the least response to interactions and showed general adaptation across the test environments. Progeny 130 had the largest 351.12 kg/palm/year of fresh fruit bunch, and negative interaction score (-2.37). Fig 5b. showed that the PC 1 and PC 2 accounted for 86.8 % and 13.2 % of variations in fresh fruit bunch yield. The biplot also revealed that progenies 130 and 119 were the best for PLG and NRT environments, and the progenies 132 and 137 for SKA.

Discussion

The analysis showed that variances due to environment (E), genotype (G) and G x E interactions were highly significant, which indicates that the test environments were diverse and the location affected yield and yield components. These results are consistent with the studies by Rafii et al. (2001, 2012); Okoye et al. (2008); Ataga (2010); and Krualee et al. (2012). This might be due to differences in rainfall by location affecting the oil palm (Fig 2.) (Corley and Tinker, 2003; Henson and Harun, 2005). Thus, access to water, including both precipitation and irrigation system supply is the main yield-limiting factor affecting oil palm (Kallarackal et al., 2004; Adam et al., 2011; Cha-um et al., 2013; Rivera et al., 2013). The biplot analysis used here allows visual interpretation of G x E interactions and genotype recommendations for multi-environment use (Fig 3, 4 and 5), showing that PC could decompose the sum of squares for the G x E interactions (Gauch, 1992). Consequently, PC1 represented the differences in yield and yield components, and environmental yield effects on PC1 enabled assessing the stability of progenies across environments (Krualee et al. 2012). It was confirmed that the G x E interactions significantly affect oil palm yield.

Materials and Methods

Plant materials and experimental details

Six DP oil palm progeny derived from an oil palm breeding program of the Faculty of Natural Resource, Prince of Songkla University, Thailand. They cross between Dura (D) females' parent and Pisifera (P) males parent, which DP was selected from the F_2 population (Eksomtramage et al., 2009). The progeny (cross numbers 110, 118, 119, 130, 132 and 137) were tested in each of three different locations (NRT, PLG and SKA) in Southern Thailand (Fig 1 and Table 1). The experiments followed a completely randomized design in five replications at each location and five palms were planted for each progeny and replication. The planting space per oil palm was 9 m equilateral triangle in each environment. The data recorded included bunch number, average bunch weight, fresh fruit bunch yield, according to trait measurements proposed by Corley and Thinker (2003). The observations were recorded from 2013 to 2014. The weather data

Table 1. description of the experimental sites.

Parameters	Environments		
	NRT	PLG	SKA
Latitude	8°13′17′′N	7°31′20′′N	7°04′47.9′′N
Longitude	99°35′5′′E	100°3′28′′E	100°13′39.7′′E
Altitude (m)	45.852	15.944	38.536
Soil texture	sandy clay loam	sandy clay loam	sandy clay

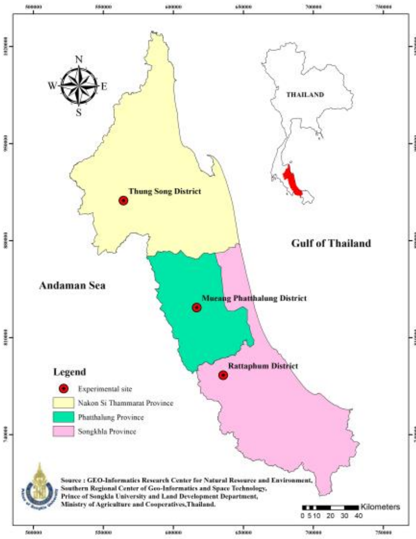

Fig 1. Map of three environments site.

Table 2. AMMI analysis of variance for bunch number, average bunch weight, and fresh fruit bunch yield, across oil palm progenies (G) grown in the 3 environments (E).

Sources of variation	df	Bunch number		Average bunch weight		Fresh fruit bunch yield	
		SS	MS	SS	MS	SS	MS
Environment (E)	2	97.36	48.67**	90.16	45.08***	39,522.00	19761.10***
Genotype (G)	5	230.99	46.19***	34.85	6.96***	71,934.00	14386.90***
G×E	10	418.51	41.85***	45.21	4.52***	76,490.00	7649.00***
PC1	6	261.27	43.55***	35.91	5.98***	66,370.53	11,061.76***
PC2	4	157.24	39.31***	9.30	2.33ns	10,119.82	2,529.95***
Residual	60	521.67	8.69	68.46	1.14	124,641.00	2,077.40

, * indicates significance at 0.01 or 0.001 level, respectively, ns; not significant.

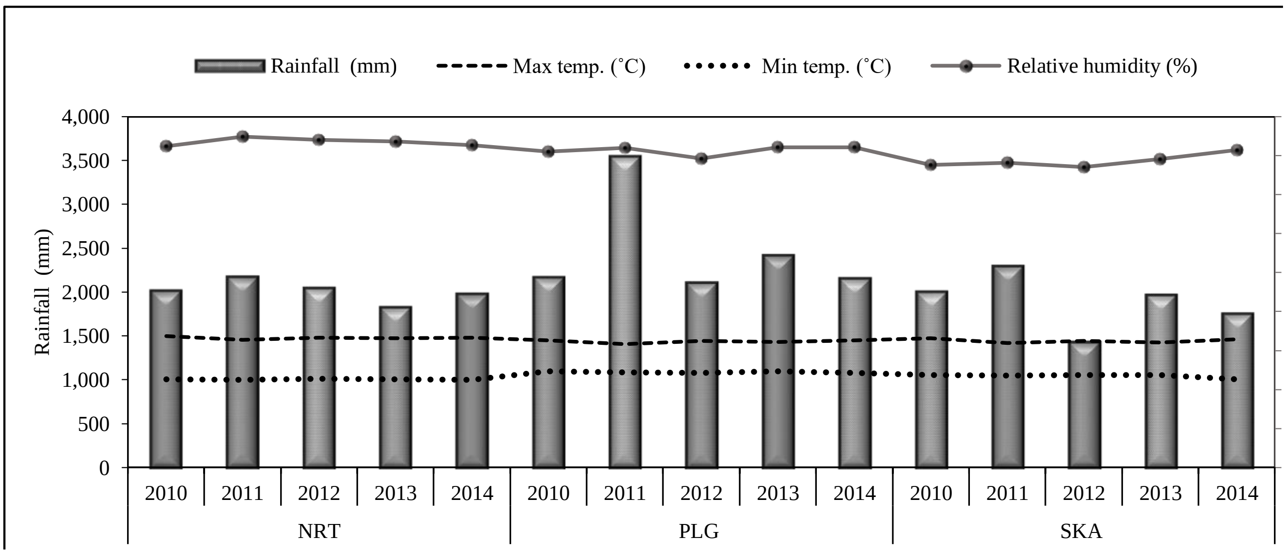

Fig 2. The annual weather data which includes rainfall (mm), average maximum temperature (˚C), average minimum temperature (˚C) and average relative humidity (%) during 2010-2014 in the three environments.

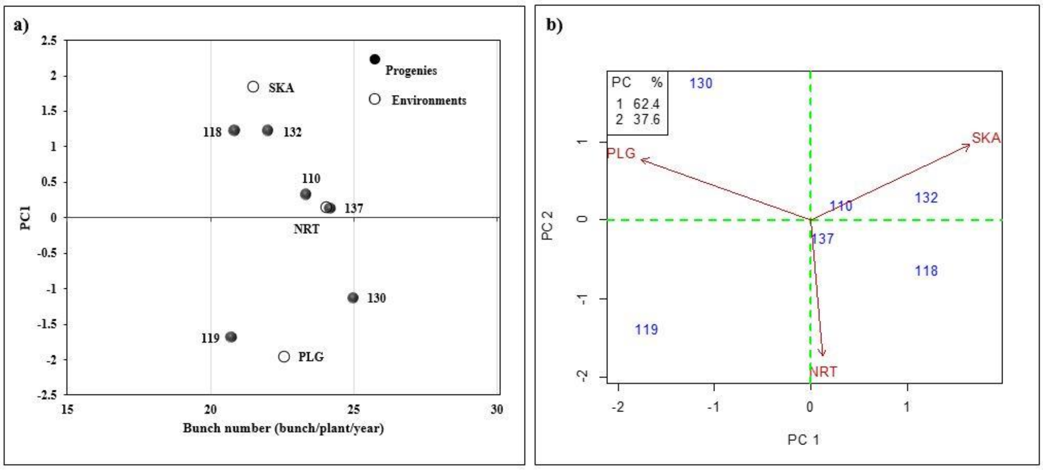

Fig 3. Biplot graph of PC1 score versus mean of bunch number (a); Biplot graph PC1 score versus PC2 score for bunch number of six oil palm progenies in the three environments (b).

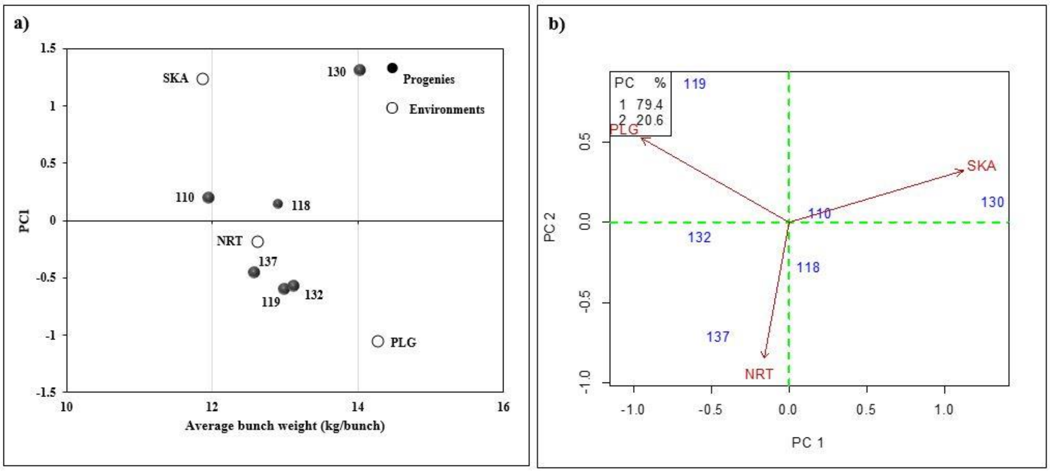

Fig 4. Biplot graph of PC1 score versus mean of average bunch weight (a); Biplot graph PC1 score versus PC2 score for average bunch weight of six oil palm progenies in the three environments (b).

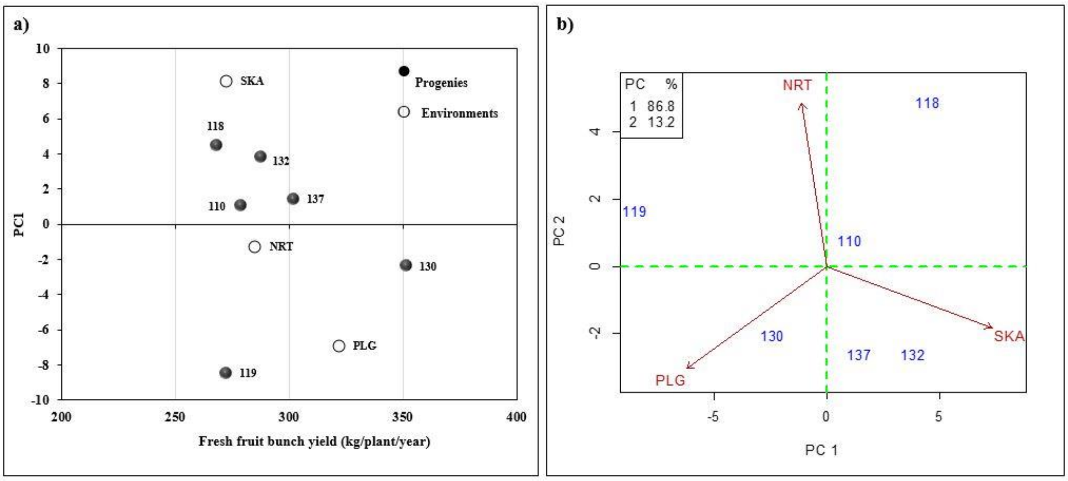

Fig 5. Biplot graph of PC1 score versus mean of fresh fruit bunch yield (a); Biplot graph PC1 score versus PC2 score for fresh fruit bunch of six oil palm progenies in the three environments (b).

(2010–2014) of the three environments was derived from the Thai Meteorological Department and summarized in Fig 2.

Statistical analysis

The AMMI model was used to analyze the G × E interactions (Gauch, 1988) based on this model:

$$Y_{ij} = \mu + \alpha_i + \beta_j + \sum \lambda_n \xi_{in} \eta_{jn} + \theta_{ij}$$

Where; Yij is trait of genotype i in environment j, μ is grand mean, αi is genotype i mean deviation, βj is environment j mean deviation, λn is singular value for PCA axis n, ξin is genotype i eigenvector values for PCA axis n, ηjn is environment j eigenvector value for PCA axis n and θij is residuals. All statistical analyses were conducted using R program version 2.14.0.

Conclusion

This study demonstrated significant G x E interactions when different genotypes (G) were grown in different locations (E, for environment). The yield and yield components of oil palm progenies were highly influenced by the G x E interactions. The AMMI biplot is an important tool for assessing the stability (insensitivity to E) and specific adaptation (best matching E). Progeny 110 had stable yield and yield components across the three environments. For maximum fresh fruit bunch yield, progeny 119 was identified as suitable for NRT environment, while progenies 130 and 132 were suitable genotypes at PLG and SKA localities, respectively. The breeding and dissemination strategies on developing new oil palm genotypes will need to address specific suitability for each environment.

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