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Original Article

Biplot analysis of agronomic and yield trait relations in Tenera oil palm (*Elaeis guineensis* Jacq.)

Niranee Bueraheng, Sitthipong Promma, and Theera Eksomtramage*

Department of Plant Science, Faculty of Natural Resources,
Prince of Songkla University, Hat Yai, Songkhla, 90112 Thailand

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Abstract

This research aimed to evaluate crosses based on multiple traits and to observe trait interrelationships in tenera oil palm. Eleven oil palm progenies were tested at Klong Hoi Khong research station, Songkhla province, Thailand. Numerous agronomic traits, yields, and yield components were recorded. The genotype by trait (GT) biplot, correlation coefficient and path coefficient were applied in multiple trait data. GT biplot graphically displayed the interrelationships among traits and facilitated visual comparison of each progenies for selection. Cross 132 and 135 were the best for bunch yield and agronomic traits respectively, whereas c119 was the poorest genotype. The useful agronomic traits correlated with yield and yield component were frond production and leaflet width, while the leaflet number proved to be an important trait as far as the average bunch weight was concerned. These traits would help to make the evaluation in the young oil palm possible.

Keywords: agronomic trait, GT biplot, oil palm, trait relationship, yield and yield components

1. Introduction

Oil palm is a valuable crop which provides the highest oil yield compared with other oil crops. Palm oil extract is useful in many ways including alternative energy or biodiesel production (Yusof, 2007). In Thailand, the planting areas in 2010 were 0.65 million hectares, most of them were planted in the south. Average yield was 14.50 tha^{-1} and 1.6 million ton of crude palm oil production. In 2017, the demand of crude palm oil for consumption and other uses is estimated to increase up to 3.2 million ton (Eksomtramage, 2011). Therefore, suitable oil palm varieties with a high oil yield are required for the enlargement of planting areas.

An important process for oil palm breeding is the performance testing of tenera derived from crossing between dura and pisifera parents. In numerous breeding programs, multi-environment trials (MET) and multiple traits have been involved to evaluate and identify the superior varieties. Oil palms are perennial crops which start to bear bunch yield at three years after field planting. For the early years, agronomic and vegetative trait evaluations are highly important. In addition, the beneficial relations of agronomic and yield traits are also restricted.

Effective interpretation and utilization of the MET data is very significant at all stages of plant breeding, including selection based on traits (Rubio, Cubero, Martin, Suso, & Flores, 2004). A genotype main effect plus genotype by environment (GGE) biplot methodology was developed for graphical analysis of MET data (Yan, Hunt, Sheng, & Szlavnics, 2000). The GGE refers to the genotype main effect (G) plus genotype by environment interactions (GE), which are two relevant sources of variation to genotype evaluation (Jenni & Yan, 2009). The GGE biplot, constructed by plotting the first two principle components (PC1 and PC2) derived from singular value decomposition (SVD) of environment–centered data, is a plot that simultaneously displays both effects of genotype and genotype by environment interaction. The concept of GGE is the same as the linear-bilinear

* Corresponding author.
Email address: theera.e@psu.ac.th

or the site regression models (SREG) and is applied for an interpretation of crossover GE interaction (Crossa, Conelius, & Yan, 2002). However, this technique can be equally used for all types of two-way data that assume as a row versus column structure. The genotypes can be generalized as rows and the multiple traits as columns. This application is also named the GT biplot (Yan & Rajcan, 2002), which allows for visualization of relationships among traits and the trait profiles of each genotypes (Yan, Kang, Ma, Woods, & Cornelius, 2007).

The objectives of this study were to describe genotype evaluation on the basis of multiple traits and to study relationships among agronomic and yield traits in tenera oil palm using GT biplot technique.

2. Materials and Methods

2.1 Plant materials and data observations

Eleven tenera oil palm crosses (c58, c77, c90, c110, c113, c118, c119, c130, c132, c135, and c137) were tested in the experiment and were derived from an oil palm breeding program of the Faculty of Natural Resource, Prince of Songkla University, Thailand. Their parents were selected from F_2 population, which was collected from the southern part of Thailand (Eksomtramage *et al*., 2009). The experiment was conducted at Klong Hoi Khong research station, Songkhla province. A completely randomized design (CRD) with four replications per treatment (1 tree/replicate) was used to determine their trait relationships during 2011 to 2012. Growth and agronomic trait measurements proposed by Corley and Thinker (2003), i.e., height, stem radius, frond production, rachis length, petiole cross section, leaf area, width, length, and number of leaflets were observed every year after transplanting, but only the third year data were applied to assess simultaneously with yield (fresh fruit bunch) and yield component (bunch number and average bunch weight) trait data.

2.2 Statistical analysis

All trait data collected were arranged as row x column structure prior to the application of the GT biplot method (Yan & Rajcan, 2002) to display the genotype by trait two-way data in a biplot. It is based on the following formula:

$$\frac{(T_{ij}-\beta_j)}{S_j}=\sum_{n=1}^{2}\lambda_n\xi_{in}\eta_{jn}+\varepsilon_{ij}=\sum_{n=1}^{2}\xi^*_{in}\,\eta^*_{jn}+\varepsilon_{ij} \quad (1)$$

where T_{ij} is the mean value of genotype i for trait j, β_j is the mean value of all genotypes for trait j, S_i is the standard deviation of trait j among genotype means, λ_n is the singular value for principal component n (PCn), ξ_{in} and η_{jn} are scores for genotype i and trait j on PCn, respectively, and ε_{ij} is the residual associated with genotype i in trait j. To achieve trait-focused scaling between genotype scores and the trait scores the singular value has to be absorbed by the singular vector for genotypes and that for traits . That is, $\xi^*_{in}=\lambda_n^{0.5}\xi_{in}$ and $\eta^*_{jn}=\lambda_n^{0.5}\eta_{jn}$. Because different traits use different units, for equation (1), the standardized data are necessary. Only PC1 and PC2 are retained in the model because such a model tends to be the best for extracting pattern and rejecting noise from the data. The GT biplot is constructed by plotting ξ^*_{i1} and ξ^*_{i2} against η^*_{j1} and η^*_{j2}. Correlation coefficients were worked out to pair-wise comparison of all studied traits and the path coefficient analysis among yield and yield components (Singh & Chaudhary, 1979) were subsequently computed. All analyses in this experiment were conducted using computer software.

3. Results

Homogeneity of variance tests indicated homogeneous error variance for each trait in the year and allowed for a combined analysis across year. Combined analysis of variance due to genotypes, year are significant ($P<0.05, 0.01$) for all the traits observed except average bunch weight (ABW). The (G × Y) interactions were significant ($P<0.05, 0.01$) for leaflet number (LN), petiole cross section area (PCS), leaflet width (LW), leaf area (LA), frond production (FP), and fresh fruit bunch (FFB). A non-significant G × Y interaction of mean squares were estimated for rachis length (RL), leaflet length (LL), height (HT), stem radius (SR), bunch number (BN) and average bunch weight (ABW) (Table 1).

3.1 Oil palm cross comparisons

Figure 1 shows a polygon view of GT biplot application constructed by drawing a polygon on crosses that were furthest from the biplot origin (0, 0). These vertex crosses are referred as either the best or worst performance in one or more traits. Perpendicular lines to each side of the polygon are drawn, starting from biplot origin. They are equality lines between adjacent crosses on the polygon to facilitate visual comparison of test crosses (Yan & Tinker, 2006). According to above information, c132 was an outstanding cross when yield traits (fresh fruit bunch and bunch number) were considered. On the other hand, most of agronomic traits (height, stem radius, frond production, rachis length, petiole cross section, leaf area, leaflet length) located in a sector where c135 is represented by the vertex cross, indicated that c135 provided the highest value for those traits while, c119 was the poorest in both yield and agronomic traits.

3.2 Oil palm trait relationships

The GT biplot with vector view (Figure 2), based on Equation 1, explained 78.40% of the total variation. A vector is drawn from the biplot origin to each marker of the traits to facilitate visualization of the relationships between and among traits, thus the correlation coefficient between any two traits can be approximated by cosine of the angle between their vectors. For example, two traits are positively correlated

Table 1. Combined analysis of variance for agronomic and yield traits in tenera oil palm showing only the degrees of freedom and mean square values.

Sources of variation	df	RL+	LN	PCS	LW	LL	LA	HT	SR	FP	BN	ABW	FFB
Genotypes (G)	10	329043.00**	1452.20**	41.25**	0.480**	6138.59**	1.336**	52398.20**	514.302**	11.077**	1106.18**	0.001ns	9328.01**
Year (Y)	1	7416.00**	63921.20**	9863.15**	25.207**	133.67**	67.387**	3113.40*	16.623**	7.617**	240.56**	4.572**	2112.06**
G×Y	10	956.00ns	558.80*	29.13**	0.135**	8.80ns	0.585**	154.80ns	0.275ns	1.871ns	23.88**	0.559ns	564.53**
Error	66	1137.00	216.70	1.06	0.004	17.20	0.005	322.60	4.569	1.409	5.23	0.341	155.17

ns: not significant , *, **: significant difference at p<0.05, 0.01 level, respectively. + RL: Rachis length, LN: Leaflet number, PCS: Petiole cross section area, LW: Leaflet width, LL: Leaflet length, LA: Leaf area, HT: Height, SR: Stem radius, FP: Frond production, BN: Bunch number, ABW: Average bunch weight, FFB: fresh fruit bunch.

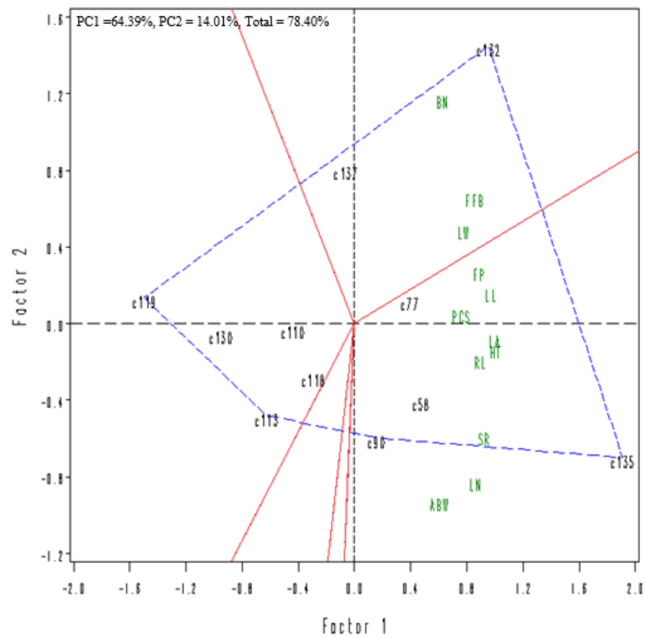

Figure 1. Polygon view of genotype by trait biplot for the experiment showing which cross provided the highest values for which traits.

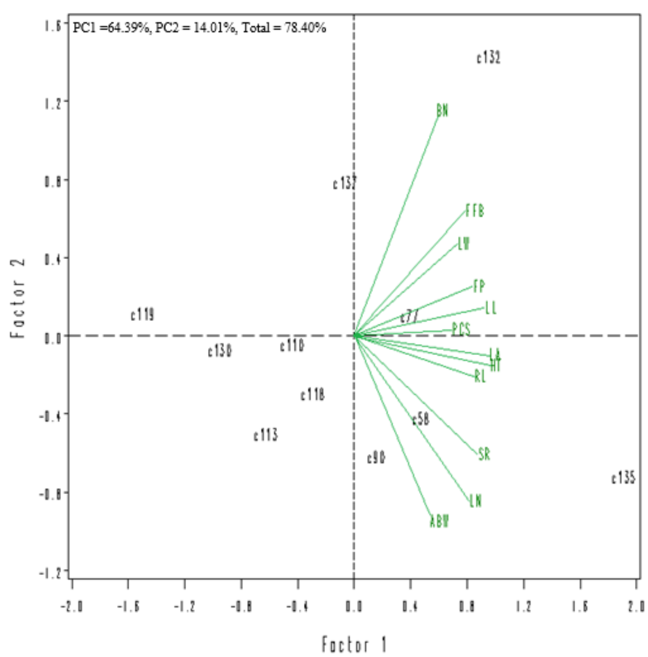

Figure 2. Vector view of genotype by trait biplot for the experiment showing the interrelationship among all measured traits in various crosses.

if their angle vector is < 90°, negatively correlated if the angle is > 90° and independent if the angle is 90°. Further, traits with longer vectors are more responsive to the crosses and vice versa (Rubio *et al.*, 2004, Yan & Rajcan, 2002).

The following can be found from Figure 2 All agronomic traits observed in oil palm were completely and

Table 2. Correlation coefficients of agronomic and yield traits in tenera oil palm.

Traits+	RL	LN	PCS	LW	LL	LA	HT	SR	FP	BN	ABW	FFB
RL	1											
LN	0.642*	1										
PCS	0.29	0.689*	1									
LW	0.640*	0.363	0.425	1								
LL	0.788**	0.653*	0.614*	0.778**	1							
LA	0.819**	0.769**	0.621*	0.831**	0.954**	1						
HT	0.872**	0.753**	0.565*	0.568*	0.833**	0.827**	1					
SR	0.756**	0.871**	0.564*	0.518	0.840**	0.872**	0.827**	1				
FP	0.557	0.632*	0.770**	0.498	0.676*	0.663*	0.718*	0.641*	1			
BN	0.378	0.101	0.461	0.519	0.551	0.434	0.543	0.195	0.653*	1		
ABW	0.535	0.745**	0.351	0.153	0.242	0.408	0.656*	0.56	0.42	-0.018	1	
FFB	0.640*	0.414	0.535	0.599*	0.639*	0.616*	0.795**	0.462	0.787**	0.883**	0.416	1

*, **: significant difference at p<0.05, 0.01 level, respectively. + RL: Rachis length, LN: Leaflet number, PCS: Petiole cross section area, LW: Leaflet width, LL: Leaflet length, LA: Leaf area, HT: Height, SR: Stem radius, FP: Frond production, BN: Bunch number, ABW: Average bunch weight, FFB: fresh fruit bunch.

positively correlated to each other, especially leaf area (LA), height (HT) and petiole cross section (PCS), as indicated by extremely acute angles. Nevertheless, no association among leaflet number (LN) and leaflet width (LW) was observed. As for the relationship between agronomic and yield traits, the most prominent relations noticed from acute angle from GT biplot revealed that leaflet width (LW) and frond production (FP) were highly positively correlated with fresh fruit bunch (FFB) and bunch number (BN), while only leaflet number (LN) was positively associated with average bunch weight (ABW). Therefore, ABW had a negative relation with the BN but independence in relation to FFB. The whole relationships derived from GT biplot were constant by correlation co-efficient analysis (Table 2). The yield components (BN and ABW) were subsequently calculated to evaluate the direct and indirect effects to FFB by path coefficient analysis (Table 3). It is clear that both of them had strong positive direct effects to FFB (0.889 and 0.438, respectively) but, showed slightly negative indirect effects to each other (-0.009 and -0.018, respectively).

4. Discussion

The vertex crosses derived from the GT biplot information based on multiple traits were c132 and c135. It was indicated that both crosses had the best performance in the experiment. However, for the advantages in oil palm breeding, these crosses were mainly different. c132 provided the finest performance for yield, i.e., fresh fruit bunch and bunch number, while c135 was the best in terms of agronomic or vegetative traits (Figure 1 and 2) These results indicated that most dry matter production of these crosses was used in different pathways (vegetative growth for c135 and yield for c132). The palm selected for high vegetative growth had little improvement in yield (Corley, Hardon, & Tang, 1971). Therefore, for the benefit of oil palm cultivation, only c132 was selected.

Fresh fruit bunch yield (FFB) is a complex trait that can be determined by its components. From both results of the GT biplot and correlation coefficient table, bunch number (BN) was the first relevant trait that has a higher influenced to FFB than the average bunch weight (ABW). Therefore, the palm that produced minimum number of bunch is likely to produce minimum FFB (Okoye & Okwuagwu, 2008; Okoye, Okwuagwu, & Uguru, 2008; Okoye, Okwuagwu, Uguru, Ataga, & Baiyeri, 2011). However, two yield components were negatively associated, so the selection of crosses that had a high bunch number would inheritably reduce the size of the bunch (Okwuagwu & Tai, 1995). These relationships were in accordance with various experiments in genetic materials of Nigeria and Malaysia populations (Kushairi, Rajanaidu, Jalani, & Zakri, 1999; Okoye, Okwuagwu, Uguru, Ataga, & Okolo, 2007). When considering from path coefficient analysis, the

Table 3. Path coefficient analysis for yield components (BN and ABW) to yield (FFB) in tenera oil palm.

Partway		
BN vs. FFB		
direct effect	=	0.889*
indirect effect via ABW	=	-0.009
correlation	=	0.880**
ABW vs. FFB		
direct effect	=	0.438*
indirect effect via BN	=	-0.018
correlation	=	0.420
Residual	=	0.180

*, ** Significant difference at p<0.05, 0.01 level, respectively.

BN also showed a stronger direct correlation to FFB than ABW (Table 3), hence the agronomic traits that were positively correlated with BN were absolutely important. Although, all agronomic traits studied had a positive correlation, only frond production (FP) and leaflet width (LW) were considered as beneficial agronomic traits because they revealed a strong correlation to BN. These relationships were in accordance with a short-stem genetic material of oil palm in Nigeria (Oboh & Fakorede, 1990). These traits would facilitate the possibility of evaluation in the young oil palm. However, oil palm is a perennial crop with an eight-to-ten-year breeding cycle (Musa, Saleh, & Loong, 2004), consecutive data from several years of agronomic and yield traits must be collected for confirming the results.

The partly different information between GT biplot and correlation coefficients in this experiment occurred because the GT biplot graphically describes the relationships among all traits based on the overall pattern of data, whereas simple correlation coefficients only describe the interrelationship between two traits (Yan & Rajcan, 2002). The GT biplot application is an effectively statistical tool for visualizing and making an interpretative comparison of crosses on the basis of multiple traits. Interrelationships among oil palm traits are clearly more informative than another conventional method such as correlation table (Dehghani, Omidi, & Sabaghnia, 2008).

5. Conclusions

The best performance cross in terms of yield production was c132, while c135 was outstanding in vegetative growth when agronomic traits were considered and c119 was the poorest cross for both bunch yield and agronomic traits. The advantageous agronomic traits which strongly correlated to yield and yield component were frond production (FP) and leaflet width (LW). Furthermore, the leaflet number (LN) was a relevant trait as far as average bunch weight (ABW) is concerned. The GT biplot is a useful statistical tool for visualizing comparison crosses on the basis of multiple traits and revealing more information of interrelationships among tenera oil palm traits.

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