International Journal of Agronomy and Agricultural Research (IJAAR)
ISSN: 2223-7054 (Print) 2225-3610 (Online)
http://www.innspub.net
Vol. 4, No. 2, p. 12-20, 2014

RESEARCH PAPER

OPEN ACCESS

Morpho-agronomic variability and GxE interactions of Manila Hemp (*Musa textilis* L. Née) genotypes grown in varying agro-ecozones in Southern Mindanao, Philippines

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Article published on February 25, 2014

Key words: *Musa textilis L. Nee*, principal component analysis, GxE interaction, Pearson's correlation, cluster Analysis.

Abstract

Taximetric statistical methods were carried out on morpho-agronomic traits from three Manila hemp (Philippine abaca) varieties planted in three locations in Southern Mindanao, Philippines. Principal Component analysis (PCA) resulted in the extraction of five principal components which collectively accounted for 99.85% of total variance. Correlation analysis revealed highly significant relationships between % survival/number of mature plants at harvest time and pseudostem height and circumference. Three – way multi-environment trial (MET) analysis resulted in the formation of two biplots which jointly revealed groupings based on component loadings. Hierarchical cluster analysis sorted the varietal entries into two groups and highlighted the divergence of Glan abaca plants from those grown in the other two sites. Similar trends for *Bongolanon* obtained for % survival and number of harvestable plants in all three locations suggests that these traits may have a very strong genetic component, but pseudostem traits were discovered to be highly susceptible to environmental conditions and as such can be manipulated to increase fiber yield. Results rationalize the selection of *Bongolanon* for wide scale propagation in Southern Mindanao. Finally, these results will facilitate recommendation of abaca genotypes with broad adaptability and/or identify suitable genotypes for targeted agro-ecozones to prevent or minimize economic losses that farmers are most likely to incur if an unsuitable abaca variety is planted on their farms.

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Introduction

Abaca (*Musa textilis* L. Née), popularly known as Manila hemp is cultivated for the fiber that can be obtained from its leaf stalks (Gonzal, 2005). Although endemic to the Philippines, it has been cultivated in other Southeast Asian countries and Central America, where it was brought by the Dutch and the Americans, respectively, as exotic introductions in the early 1900s (FIDA, 2012; PCARRD, 2008). In 2004, Daimler Chrysler made public its plans of using Philippine abaca for exterior lining of its Class A cars such as Mercedes Benz and Plymouth (Bledzki *et al.,* 2004). Demand for abaca is expected to grow in the coming years because of the declining supply of wood resources. In spite of the growing demand for abaca, however, local production cannot cope with market demand. Productivity is generally low in typhoon-ravaged and virus-infested old abaca plantations in Luzon and Visayas, the major abaca- producing regions of the Philippines (Dizon *et al.,* 2012).

Prevalence of viral diseases affecting abaca plantations in Luzon and Visayas highlighted the potential of Mindanao as a major source of abaca. The highly diverse terrain and climatic conditions in Mindanao however, constrain abaca production in this region. METs should be imperative in the selection of a specific variety for massive planting efforts in Mindanao. However, complexities arising from GxE interactions (GEIs) in multilocational field trials seriously impair the accuracy of yield estimates, rendering the selection of suitable materials for mass propagation and crop improvement programs difficult (Becker and Leon, 1988; Purchase *et al.,* 2000).

The Fiber Industry Development Authority(FIDA) is the Philippine government agency mandated to undertake abaca studies and to fill the demand gap for abaca through massive planting in more areas which have very low volume of production (FIDA, 2012). In Region 12 specifically, production volume is very low (2%) when compared to overall Mindanao production. To address fiber shortage, FIDA recommended *Maguindanao, Tanggonon* and *Bongolanon* varieties to Mindanao abaca farmers though no METs on these varieties had been done. In fact, there is scanty literature about the crop and studies available mostly dealt with genetic diversity, paternity testing and genetic transformation of abaca for viral resistance (Zapico *et al.,* 2010; Dizon *et al.,* 2012). In Southern Mindanao alone, Zapico and her colleagues (2010) recorded 110 abaca varieties during their various field sorties. Particularly relevant in this study was the divergence of 2 Maguindanao strains in Tboli, South Cotabato which can be ascribed to pseudostem traits and sap color.

This present study investigated the field performance of these three abaca cultivars with the objectives of identifying consistently performing varieties across locations and elucidating GEIs that underpin their growth responses. This study will aid in the identification of varieties suited to specific ecological niches, in maximizing fiber yield and will consequently obviate economic losses by farmers due to wrong varietal choice. Growth performance of the three varieties across diverse eco-zones will also provide information that can be utilized in crop improvement efforts for increased fiber yield. Results of the study are therefore expected to narrow gaps in the current state of knowledge about abaca and provide farmers and stakeholders with relevant information in the selection of varieties that while high-yielding may also exhibit high adaptability and survival to local farming conditions.

Materials and methods

Physico-chemical Characterization of the Study Sites

Three abaca varieties were planted in three sites in Southern Mindanao characterized by altitudinal differences and diverse agro-ecological condition (Figure 1). The first study site was Barangay Upo, Maitum, Sarangani province (6°02′N, 124°29′E) with an altitude of 54 m above sea level (Table1a). Average monthly rainfall in Brgy. Upo during the study period was 93.37 mm. It was also observed that the soil in the study site was of the silty-clay type, with 5.5 pH and minimal organic matter content (3.5%). It also had excessive potassium/ phosphorus content while deficiencies were noted for zinc, copper, iron and manganese (Table 1b).

The second site was Lake Lahit, Lake Sebu (N 06°14.676' and E 124° 42.625') with an elevation of 775 m above sea level (asl). Belonging to the 4th type climate classification in the Philippines, Lake Lahit had more or less evenly distributed rainfall and an average monthly precipitation of 232.95mm during the study period. Soil analysis revealed the soil in the study site to be a light-textured silty loam with a pH of 5.6 (Table 1b). It also had an organic matter content of 3.5% and deficiencies for potassium, copper, manganese and zinc. Levels of phosphorus and iron were found to be excessive.

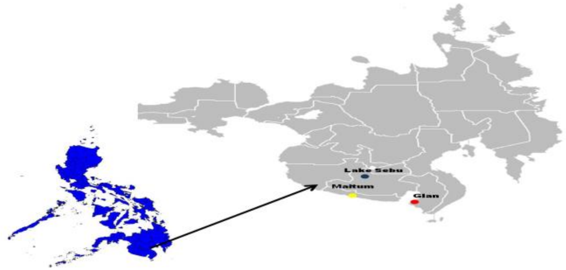

Fig. 1. Map of Southern Mindanao, Philippines showing 3 study locations.

The third site was Barangay Small Margus, Glan, Sarangani Province (N5^{0} 39.588', E125^{0} 18.832') with an altitude of 44 m above sea level. The coconut grove where the three varieties were intercropped was in a neglected state and had clay loam soil, a pH of 5.6 and very low levels of organic matter (1.7%), manganese, iron, copper and zinc (Table 1b). Potassium levels on the other hand were way above average (1625 ppm). Belonging to Type IV climate, annual rainfall in Small Margus is usually 79.6 mm with 78% relative humidity. During the study period however, the amount of precipitation ranged from a very low 10 mm in December to a very high 317 mm from August to September.

Multilocational Testing of Three Abaca Varieties

Disease-free abaca planting materials of three abaca varieties(*Tangonon, Bongolanon* and *Maguindanao*) were planted in ~1,000 m^2 blocks at a distance of 3 x 3 m in three different farming conditions/locations in Glan, Maitum and Lake Sebu following the Randomized Complete Block Design (RCBD) replicated 10 times with 1m alleys in between blocks. Each block consisted of 30 hills with 10 hills each for *Tangonon, Bongolanon* and *Maguindanao*. After the abaca suckers had become acclimatized in the three planting sites after about one month, agronomic data such as total plant height and pseudostem height (leaves not included), average number of suckers, number of harvestable plants, base and tip circumference of stalks were gathered on a monthly period for nine months. Data on the percentage survival of the three abaca varieties in the three locations were also recorded during the duration of the research.

Data Analysis and Interpretation

Data obtained from the three planting sites were subjected to parametric and multivariate statistical analyses viz. principal component analysis, cluster analysis and Pearson's Correlation to elucidate the nature of morpho-agronomic similarities/dissimilarities and the GEIs of the three abaca varieties. Principal component analysis, based on a correlation matrix was performed and Varimax rotation of the extracted component axes was done to facilitate the assembling of tested variables into specific PC/s. Three-way MET data analysis (Genotype x Environment x Trait) yielded two biplots which graphically addressed questions about GEIs. Pearson's correlation coefficient was also computed and the data were then subjected to a hierarchical clustering algorithm based on squared Euclidean distances and using average linkage (UPGMA). All analyses were run on the PASW v. 18 and XLSTAT pro 7.5 statistical platforms.

Results

Growth Performance of 3 abaca varieties in 3 locations

Growth responses of the three abaca cultivars were seen to vary in the different planting sites though some traits were consistent across locations. For example, *Bongolanon* had the highest values for survival % and number of harvestable plants in all three sites implying a relatively high level of adaptability and hardiness for this variety. It was also observed that except for Glan plants, values for stalk characteristics of *Tanggonon* and *Maguindanao* were highest in Lake Sebu and Maitum respectively. For all three sites, heavy rainfall patterns during the first four months were observed to cause inhibitory effects on plant growth across varieties and led to widespread *Cordana musae* outbreak and stalk dieback. Another common problem in all three sites was poor soil quality which became manifested in abaca plants through different displays of mineral deficiencies and toxicities (Table 1b).

Table 1. Physico-Chemical Characterization of the Study Sites.

Location	Altitude (asl)	Mean Temp. (°C)	Mean Rainfall (mm)	Soil Type	Soil pH	Organic Matter Content (ppm)	Phosphorus (ppm)	Potassium (ppm)	Copper (ppm)	Iron (ppm)	Manganese (ppm)	Zinc (ppm)
Glan, Sarangani Province	44m	28	157.36	Clay loam	5.6	1.7 ^{BA}	20 ^{B}	1625 ^{AA}	1.87 ^{WBA}	11.61	17.76 ^{BA}	0.37^{VL}
Maitum, Sarangani Province	54m	29	93.37	Silty clay	5.5	2.1 ^{BA}	27 ^{B}	1575 ^{AA}	2.46 ^{WBA}	126.4	20.93 ^{WBA}	2.0 ^{BA}
Lake Sebu, South Cotabato	775m	27	232.95	Silty loam	5.6	3.5 ^{BA}	20 ^{B}	230 ^{BA}	1.065 ^{WBA}	14.48	23.67 ^{VL}	0.51^{BA}

Pearson's Correlation Analysis

Pearson's correlation analysis showed very high positive correlation between number of harvestable plants/ survival rate($r=0.959^{**}$) and pseudostem height/body circumference($r=0.880^{**}$) at $p<0.01$ (Table 2). These very high correlations between survival rate/number of harvestable stalks and those between stalk characters can be used for more efficient abaca improvement programs since prior knowledge of high correlations between traits would reduce the number of traits to be measured (Hansche *et al.,* 1972). Significant positive correlations were also observed for pseudostem height/plant height, base circumference/plant height and body circumference/plant height ($p<0.05$).

Table 2. Pearson's Correlation.

	Plant Height	Suckering Ability	Pseudostem Height	Circumference Base	Circumference Body	No. of harvestable plants	Survival Rate
Plant Height	1						
SuckeringAbility	.397	1					
Pseudostem Height	.764*	.184	1				
Circumference Base	.735*	.399	.535	1			
Circumference Body	.776*	.379	.880**	.561	1		
Harvestable plants	.586	.024	.190	.374	-.015	1	
Survival	.539	-.074	.098	.201	-.046	.959**	1

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Principal Component Analysis

PCA yielded five principal components (>1.0 eigenvalues) which accounted for approximately 99.85% of total variance (Table 3). Breakdown of this cumulative variance revealed contributions of 51.6%, 27.6%, 12.6%, 6.2% and 1.8% for PC1, PC2, PC3, PC4 and PC5 respectively. PC 6 and PC7 were discarded because of very low variance contributions (0.007 – 0.143). Of the five retained PCs, the first principal component (PC1) was of foremost importance since it had a latent root (eigenvalue) of 3.6 and accounted for 51.6% of total variability in the data set. Table 4b shows that the variable with highest loadings on PC1 was circumference body (≥0.9). Circumference base, pseudostem height and plant height also made substantial contributions to PC1 (absolute values ≥0.7). On the other hand, PC2 which had an eigenvector value of 1.9 contributed 27.6% to total variance. Variables such as percentage survival and number of mature/harvestable plants made noteworthy contributions to this principal component (≥0.9). Moreover, the scree plot (Figure 2) generated justified the extraction of PCs 1-5. Cattell (1966) pointed out that retention of PCs should be based on the gradually downward sloping line (which corresponds to a gradual decrease of eigenvalues) up to the point where the line appears to level off. In the scree plot, the relatively flat line linking PC6 to PC 7 suggests minimal deviation from total variances calculated and provides rationalization for their being discarded.

Table 3. Computed Eigenvalues for the Seven Principal Components.

COMPONENT	INITIAL EIGENVALUES		
	Total	% of Variance	Cumulative %
1	3.612	51.604	51.604
2	1.931	27.587	79.191
3	0.885	12.646	91.837
4	0.436	6.231	98.068
5	0.125	1.783	99.85
6	0.01	0.143	99.993
7	0	0.007	100

4a. Rotated Component Matrix Values for Abaca Genotypes.

Study Sites	Component	
	1	2
Lake SebuTanggonon	0.862*	0.505
Lake Sebu Maguindanaon	0.915*	0.404
Lake Sebu Bongolanon	0.881*	0.472
Maitum Tanggonon	0.341	0.94*
Maitum Maguindanaon	0.307	0.952*
Maitum Bongolanon	0.362	0.932*
Glan Tanggonon	0.964*	0.264
Glan Maguindanaon	0.973*	0.231
Glan Bongolanon	0.934*	0.355

Tables 4a-4b. Rotated Component matrices for Abaca genotypes (4a) and evaluated traits (b).

Three-way MET data analysis resulted in the formation of two-way tables which were then individually studied in biplots. While the biplots generated were not equally important, complete insight into MET data can only be achieved with their full understanding. The *Genotype x Environment* biplot (Figure 3) shows the projection of the abaca genotypes in the reduced space determined by PC1 and PC2 axes. It can be seen that all abaca cultivars clustered in the upper right portion of the biplot while those from Maitum occupied a more central position due to high Prin 2 and low Prin 1 values for the latter. *Tanggonon, Bongolanon* and *Maguindanao* cultivars from Lake Sebu and Glan formed another group towards the right of the biplot by virtue of high Prin 1 and low Prin 2 scores.

4b. Rotated Component Matrix Values for Evaluated Traits.

Evaluated Traits	Component	
	1	2
Plant Height	0.832*	0.531
Suckering Ability	0.551	-0.095
Pseudostem Height	0.866*	0.104
Circumference Base	0.747*	0.296
Circumference Body	0.946*	-0.079
No. of harvestable plants	0.099	0.984*
Survival	-0.005	0.985*

The *Genotype x trait* biplot (Figure 4) shows groupings of the evaluated traits in rotated variable space. The clustering of %survival and number of harvestable plants can be attributed to high Prin 2 and low Prin 1 values. Moreover, the narrow angle between these two variables indicates that they have similar response patterns for the three varieties across different environments. Similarly, acute angles can be noted for suckering ability/circumference body, suckering ability/pseudostem height and plant height/circumference base.

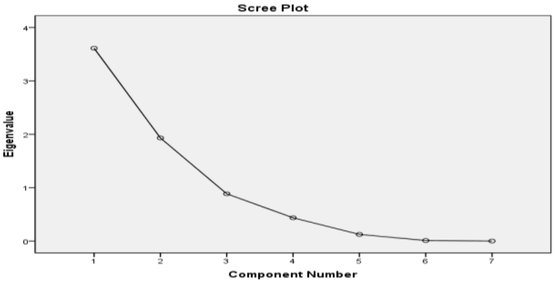

Fig. 2. scree plot of Eigenvalues and Principal component number.

Cluster Analysis

Figure 5 shows results of hierarchical cluster analysis (HCA) of morpho-agronomic data using UPGMA which resolved the different varieties into 2 distinct clusters and highlighted the divergence of cluster 1 (composed of Glan plants) from cluster 2 (Lake Sebu and Maitum plants). Intracluster composition of cluster 1 which shows the divergence of *Bongolanon* (subcluster 1b) from *Tanggonon* and *Maguindanao* (subcluster 1a) is due to highest values that the former variety obtained for plant height, pseudostem height, survival % and number of mature plants. Moreover, dendrogram truncation at the 3-cluster level (5 Euclidean units) grouped the abaca plants according to their places of origin. The clustering mechanism further caused the resolution of subclusters 2a and 2b through the separation of *Maguindanao* from the other varieties in Lake Sebu and Maitum.

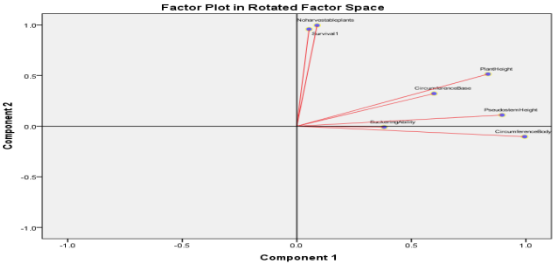

Fig. 3. Genotype x Trait Biplot representing 3 abaca varieties measured for 7 Traits.

Discussion

There is a wealth of methods available for the analysis of METs each with specific strengths and weaknesses. Smith *et al.* (2005) described in detail the inadequacies of ANOVA while extolling the virtues of mixed model analysis to clarify GEIs in crop studies. Correlation analysis has been used in tandem with other statistical methods to explain GEI in a number of studies (Lu and Wu, 1987; Perkins and Jinks, 1968). The use of PCA biplots for GEI was also reported by Kempton (1984), Gabriel (1971), Flores *et al.* (1998), and Yan and Kang (2003) while Kaya *et al.* (2006) and Karimizadeh *et al.* (2012) used cluster analysis to explain GEIs in bread wheat and durum wheat respectively.

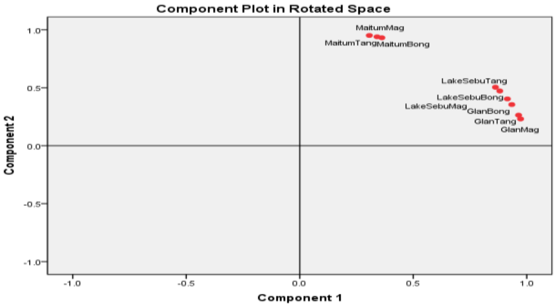

Fig. 4. Genotype x Environment Biplot showing GxE Interactions of between 3 abaca genotypes in 3 location.

For this study, PCA summed up total variance and quantified actual contributions of each trait to variability in this specific data set while three-way MET biplots used for analysis justified the separation of Maitum varieties according to %survival and number of harvestable plants. These two traits were also found to exhibit very high correlation with each other (r=0.959) and to have contributed extensively to PC2 (≥0.9). HCA sorted the varieties according to their places of origin and highlighted the divergence of Glan-grown varieties from the abaca varieties in the other sites. These groupings which can mostly be attributed to high Prin 1 values were associated with stalk characteristics. Moreover, visual inspection revealed that plants grown in Glan were considerable smaller and thinner when compared to those in the other sites.

Collected data also revealed that stem-related characters manifested site-specific patterns of expression for *Tanggonon* and *Maguindanao* in Lake Sebu and Maitum respectively. On the other hand, high values for % survival and number of harvestable plants for *Bongolanon* were consistent across locations suggesting that an active genetic mechanism controls these traits. FIDA recommendation about Bongolanon as a suitable planting material for Southern Mindanao is supported by these results. As for Maguindanao and *Tanggonon,* extensive field trials should be conducted before they can be recommended for a particular site. *Tanggonon*, specifically had been found to have poor adaptive capacity and as such can only thrive well in certain locations.

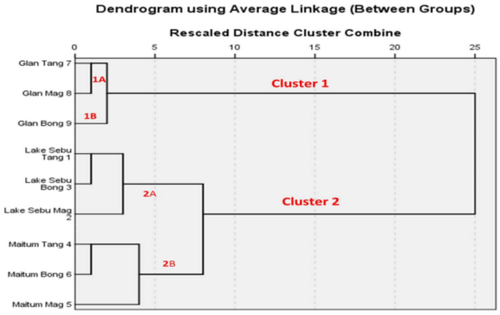

Fig. 5. Dendrogram of abaca genotypes generated using UPGMA.

Conclusion

This study provides sound basis for the Philippine FIDA recommending *Bongolanon* for abaca expansion programs in Mindanao. Results of the study however provide evidence that *Maguindanao, Tanggonon* do not exhibit adaptability to the vast range of conditions in the Southern Mindanao landscape and are therefore suited only to specific agro-ecological conditions. Moreover, traits that are critical for the successful establishment of the plant (%survival and number of harvestable plants) are seemingly genetic in nature whereas those that affect yield (pseudostem characters) are profoundly influenced by the environment. More studies are however warranted to unequivocally establish these findings.

The combined use of Pearson's Correlation, HCA and PCA provided adequate explanation for the nature of growth responses of the abaca varieties across locations. These analyses can be used as a basis for the selection of suitable parental materials for improved agro-morphological traits and of suitable cultivars for mass propagation in Mindanao. These results, however, are inconclusive owing to the small number of traits evaluated and the poor state of the soil in the study areas. To accurately explain the adaptability patterns of three abaca varieties, the problems on soil pH and deficiencies/toxicities should be addressed prior to field testing. Lastly, it is also recommended that this study will be conducted using more morpho-agronomic characters encompassing the entire life cycle of the plant.

Acknowledgments
The invaluable help extended by FIDA field technicians and abaca farmers during field work is gratefully acknowledged. Heartfelt gratitude is also due to FIDA director, Dr. Olympio Macarayan for mobilizing the field personnel of FIDA regions 11 and 12 for the realization of this study.

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