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Full Length Research Paper

Correlation between morphological characters and estimated bunch weight of the Tropical banana cultivar

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The objective of this study was to measure and identify the variables that have more influence on bunch weight (BW), and determine a statistical model for predicting yield for the Tropical banana cultivar (cv.). The experiment consisted of a uniformity trial, conducted in Guanambi, Bahia, with a total of 360 plants of the Tropical cultivar YB42-21 (AAAB) in an area of 2,160 m^2. The vegetative characteristics such as plant height, pseudostem circumference, number of children (suckers) produced and number of green leaves at flowering and harvest, and yield characteristics such as BW, number of hands and fruits, weight of the second hand, length and diameter of the fruit were assessed in two growing seasons. In the evaluation, each plant was considered as a basic unit with an area of 6 m^2, thus, there was a total of 360 basic units. The variables that correlated with the weight of the bunch are: average fruit weight (FW), weight of the rachis, number of fruits per bunch, fruit length (FL) and number of leaves at harvest. The methodology of multiple linear regression (MLR) was used to estimate bunch weight. The most significant variables that were measured included number of leaves at harvest, number of fruits per bunch, FW, FL, rachis weight (RW) and stalk length (SL), generating the following prediction equation: BW= -5.249 + 0.11NLH + 0.066NFB + 0.046FW + 0.183FL + 2.039RW -0.011LS.

Key words: *Musa* spp., production, banana, regression model.

INTRODUCTION

Banana is a tropical fruit and the most important food to the population of both rural and urban areas. Its cultivation is very significant in the tropical areas where agroecological agricultural systems are practiced. It is considered an important food because of its chemical composition and high content of vitamins and minerals, particularly potassium; it is considered to be the most consumed fruit, both for its versatility in terms of modes of consumption (processed, fried, cooked, fresh) and its characteristic flavor, aroma, natural hygienic packaging and the fact that it could be eaten fresh (Silva et al., 2002).

In order to have better knowledge of crops' responses to their environment, statistical models are used as tools of great importance for analyzing cultivated systems,

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Abbreviations: BW, Bunch weight; **FW,** fruit weight; **FL,** fruit length; **MLR,** multiple linear regression; **RW,** rachis weight.

allowing for the study and understanding of the set, estimating the performance of crops in different areas and situations and describing the behavior of different types of traits in relation to the plant of interest (Silva et al., 2002). Identifying, describing and predicting the relationships between processes involved in the development of the banana plant is of fundamental importance. One way of doing these is to find out models that correlate the variables which describe the reality, assessing the possible relationship between a dependent variable with one or more independent variables. This can be achieved by using linear regression models.

Although several studies have been conducted on banana plant mainly in Brazil in recent years, technical information needed for the understanding of the impact of its vegetative characteristics on final yield is still lacking (Rahman and Bala, 2010). Consequently, the simulation model comes in handy as a useful tool for predicting the variability of income according to the variables (Gungula et al., 2003).

Predicting the development of a particular cultivar base d on vegetative and yield characteristics is a common practice (Jame and Cutforth, 1996). Statistical modeling is used to estimate the duration of stages of plant development, choose the time of planting, determine the probable dates of harvest, predict an abnormal production, thus, providing data that could be used in breeding programs and offering the producer a tool that will assist in developing management plans (Roberto et al., 2005; Stenzel et al., 2006). In view of the foregoing, it is necessary to develop equations for the production process and estimate the parameters involved.

The concept of multiple regression has been applied to several plant species such as wheat (Le Bail et al., 2005), sugarcane (Scarpari and Beauclair, 2004, 2009), corn (Soler et al., 2007), strawberry (Antunes et al., 2006), orange (Stenzel et al., 2006) and rice (Streck et al., 2007) in order to estimate their yield and production. In a few studies on banana, the focus was on characterizing and evaluating the behavior of genotypes (varieties and hybrids) through the use of phenotypic descriptors relevant to the identification and selection of superior individuals. However, no work on statistical modeling of bunch weight (BW) has been done. It is, therefore, the objective of this research to measure and identify which variables have the most influence on bunch weight, and determine a statistical model which can be used to predict yield for the Tropical banana cv.

MATERIALS AND METHODS

Planting and management of the crop

For the experiment, we used micropropagated plants transferred from Embrapa cassava and fruits, multiplied by the Biotechnology Field in Biofactory Cruz das Almas, Bahia, Brazil, acclimatized to tubes, and transported to the site of the trial wound with roulade type packaging from where they were transplanted directly to the field.

The experiment consisted of a test of uniformity with the Tropical cv. YB42-21, tetraploid hybrid derived from the Yangambi nº 2, AAAB genomic group, resistant to yellow Sigatoka and tolerant to Panama disease, and similar to apple fruit generated and selected by Embrapa cassava and fruits. The planting area consists of 11 rows of 52 plants each with a spacing of 3×2 m, making a total of 572 plants and 3.432 m^2 floor area. However, only the 9 central rows with 40 plants each totaling 360 plants and an area of 2,160 m² were used for the study. In the evaluations which were carried out in two production cycles, each plant was considered as a basic unit (bu) with an area of 6 m². This means that 360 bu were used for experiment. The irrigation system used was fixed sprinkler sub-canopy sprinklers. The management of the irrigation was calculated by the method of irrigation pre-set based on average Class A pan evaporation measurements in Codevasf Meteorological Station, the coefficients of crop cultivation (Heslop-Harrison and Schwarzacher, 2007), the characteristic hydro-physics of soil and irrigation system.

Evaluations

The evaluations were conducted during the flowering stage and before the stage of bunch harvesting in the production cycles of the mother plant and sucker. The phenotypic descriptors and vegetative yield were measured following the methodology proposed by Silva et al. (1999) and presented subsequently.

Vegetative characters

a) Plant height (PH)
b) Pseudostem perimeter (PP)
c) Number of leaves at flowering (NLF)
d) Number of shoots issued to flowering (NSF)
e) Number of leaves at harvest (NLH)

Yield characteristics

The characteristics of yield were assessed at the time preceding the harvest of the bunches. The harvest date was based on fruit diameter (FD) or caliber of the external row of fruits of the second hand, considering the peculiarity of the hybrid (type of fruit). The following are the characteristics of yield:

a) BW – the whole bunch structure was evaluated (bunch, stalk and rachis)
b) Total number of clusters by bunch (NCB)
c) Number of fruits per bunch (NFB)
d) Second bunch weight (SBW) – this is the reference bunch.
e) Fruit weight (FW) - the mass of the fruit or central finger in the external row of fruits of the second bunch (reference bunch) was obtained individually from each bunch.
f) Fruit Length (FL) - the measurement was on the external curvature of the fruit or central finger in the external row of fruits in the second bunch from the base to the apex of the fruit (disregarding the peduncle and the apex of the fruit).
g) FD - measured in millimeters at the middle part of the central fruit in the outer row of the second bunch, using a caliper. This diameter or side calibration of the fruit was used as a criterion for the harvest.
h) Rachis weight (RW) - the mass of the rachis was obtained individually from each bunch.
i) Stalk length (SL) – the curvature of the stalk was measured from its insertion in the pseudostem to the male inflorescence.
j) Stalk diameter (SD) – measured in millimeters using a caliper at the middle part of the bunch.

Table 1. Components of the prediction equation of the bunch weight of the Tropical banana cultivar plant as a function of variables measured at the flowering stage.

Constant	Coefficient					
	PH	PP	NLF	NCF	R^2	CV (%)
+3.783	-0.009	+0.131	0.231	-	0.13	16

PH, Plant height (cm); PP, pseudostem perimeter (cm); NLF, number of leaves at flowering; NCF, number of children (suckers) sent to flowering; -, non-significant variables by stepwise procedure.

Statistical analysis

To assess the significance of the variables related to vegetative and yield characteristics which influence the weight of the bunch, a regression equation was applied using the procedure called stepwise selection of variables (Draper and Smith, 1981) and software R (R Development Core Team, 2010). The model of multiple linear regression (MLR) can be adjusted as:

$$Yi = + \beta_0\ \beta_1 X_{1i} + \beta_2 X_{2i} + ... + \ \beta_k X_{ki} + \varepsilon i \qquad (1)$$

Where, *Yi* refers to the sum of BW determined by the variables of vegetative and yield characteristics (X_i, ..., X_k), respectively such as PH, PP, NLF, NSF, NLH, and NCB, NFR, PP, FW, FL, FD, RW, SL and SD; ε_i is the error associated with the observation which is assumed to be normal and independently distributed; β_0 is an inherent constant in the model, while β1, ..., βk are model coefficients. The coefficient of determination was determined by the formula:

$$R^2 = \frac{SQReg}{SQT} = 1 - \frac{SQR}{SQT} \qquad (2)$$

where $0 \leq R^2 \leq 1$

To elucidate the relationship of each variable that correlated with the final BW in the regression analysis, Pearson's correlation was used (Draper and Smith, 1981).

RESULTS AND DISCUSSION

Statistical operations were performed to estimate the prediction equation of the weight values of the bunch of the Tropical banana cv. (only significant variables were selected) taking into account the coefficient of determination (R^2 Equation 2) equations for the set predictions in each case and the analysis of correlation between variables.

The prediction equation obtained by MLR which was the best fit for measuring the variables BW at flowering showed a coefficient of determination (R^2) of 0.13. Table 1 shows the constant and estimates of the coefficients of the variables forming the equation that uses the composition of PH, PP, NLF and NCF.

The adjustment of this equation with R^2 of 0.13 may have been due to the little influence that each variable had on the final weight or due to the reduced number of variables (vegetative characteristics) that make up this model, which shows that a series of other factors not considered in this study may influence the weight of the bunch. The value of R^2 was low despite the fact that the coefficient of variation was relatively low (CV = 16%). Donato et al. (2006a) noted that the traits measured at flowering, such as plant height and pseudostem circumference were significant in relation to the prediction of BW of the genotypes Prata anã and Pacovan (AAB), Cavendish: Grande naine and Nanicão (AAA), the hybrid type Silver: PA42-44 (AAAB), Preciosa, Japira, Pacovan-Ken and ST12-31 (AAAB) which are all generated and selected by Embrapa cassava and fruits, and the Gros Michel type: Ambrosia, Calypso and Buccaneer (AAAA) and hybrid type Cavendish FHIA 02 (AAAA). However, this study did not satisfactorily establish the equation for predicting the weight, but rather the relationship between the characters.

In the case of variables measured at the time preceding harvest, the best adjustment equation to determine the BW at harvest was: BW = -5.249 + 0.11 NLH + 0.066 NFB + 0.046 FW + 0.183 FL + 2.039 RW - 0.011 SL with R^2 of 0.71, while the other variables were not significant (Table 2). The fact that the coefficient of determination of this model is high, despite a low coefficient of variation (9%) is an indication that the variables measured in the production phase may represent more accurately the weight of the bunch. To more accurately estimate the BW, other attributes such as soil and climate can be evaluated in future research which may give rise to a higher coefficient of determination. Pinto (2002) who studied the prediction of the incidence of rust in coffee also found in the adjusted model regression analysis a low coefficient of determination (0.55 to 0.60), though the variables were significant. In using equation to predict BW, the producer or breeder may use the variables that were significant to the model to predict the BW before the bunch is harvested, so as to estimate the production that allows for the development of management culture plans.

Descriptors of bunch weight and hands, although expressing productivity directly, cannot be considered in isolation when choosing a cultivar, like other characters related to fruit such as weight, length, diameter and flavor (Silva et al., 2002). This implies that the study of prediction associated with the correlation can discriminate which variables influence the production in order to determine the magnitude and significance of associations between phenotypic descriptors, and thus, give

Table 2. Components of the prediction equation of the bunch weight of the Tropical banana cultivar in relation to variables measured at the stage prior to harvest.

Constant	Coefficient											
	NLL	NCC	NFB	SBW	FW	FL	FD	RW	SL	SD	R^2	CV (%)
-5.249	+0.11	-	+0.066	-	+0.046	+0.183	-	+2.039	-0.01	-	0.7	9

NLL, Number of living leaves; NCB, number of clusters by bunch; NFB, number of fruits per bunch; SBW, second bunch weight (g); FW, fruit weight (g); FL, fruit length (cm); FD, fruit diameter (cm); RW, rachis weight (g); SL, stalk length (cm); SD, stalk diameter (cm).

Table 3. Correlation coefficients of the relationship between variables measured at flowering and BW of the Tropical banana cultivar.

Parameter	BW	PH	PP	NLF
BW	1.000	-	-	-
PH	0.857	1.000	-	-
PP	0.025	0.153	1.000	-
NLF	-0.317	-0.178	0.118	1.000

BW, Bunch weight (kg); PH, plant height (cm); PP, pseudostem perimeter (cm); NLF, number of leaves at flowering.

information to the breeder about which characters have more influence on the final weight. Further research may be carried out on how to improve final weight.

The correlations between BW and the characteristics observed at flowering such as plant height, pseudostem circumference, number of leaves at flowering and number of suckers sent to flowering as well as the correlations between them are presented in Table 3. In the correlation analysis performed in this study, only significant variables in the MLR were used for the prediction of BW.

The relationship between BW and plant height was significant and positive, which means that the weight varied directly with the size of the plant. Plant height is an important descriptor from the standpoint of phytotechnical improvement; therefore, it influences the aspects of plant density and crop management, interfering with the production (Donato et al., 2006b). Generally, in banana, regardless of the genomic group, the lowest groups of sorghums are more productive than the highest-sized ones (Donato et al., 2006b). The Tropical cultivar is considered medium-sized (3.0 to 4.5 m) and in accordance with the correlation analysis, there is a direct relationship of height growth with production, even if this condition is not significant.

The estimated correlation between bunch weight and girth of the pseudostem was not significant and positive, which may indicate that regardless of the thickness of the pseudostem, bunch weight may be of satisfactory value. This result agrees with that of Donato et al. (2006b) who obtained the same result for all genotypes tested, both the first and second cycles.

The relationship between bunch weight and number of leaves at flowering was significant and negative, which shows that the weight varied inversely to the number of green leaves. Because this correlation was low, but significant, it is probable that the degree of relationship between these variables is not strong enough to reflect the weight since the leaves serve as sources of carbon skeletons for fruit formation, and consequently, higher leaf area increased the area for the performance of photosynthesis. Significant positive relationship was found by Donato et al. (2006b) between BW and NLF for PV42-68 and Grande naine (second cycle), PV42-142, PV42-85, Calypso and PA42-44 (first cycle), while no significant relationship was found with other genotypes.

The correlations between BW and the characteristics seen at the time preceding the harvest such as fruit length, average fruit weight, number of fruits per bunch, rachis length, rachis weight, number leaves at harvest, which were significant in the analysis regression are shown in Table 4. The bunch weight in relation to the external FL showed a significant and positive correlation, indicating that the weight varied directly to FL (0.340). The analyses of the external and internal lengths give an idea of the curvature of the fruit. However, since this study used only the FL, the relationship of the weight to length is same as the fruit shape. The prevalence of significant and positive values indicates the existence of a genetic association between BW and FL (Donato et al., 2006a).The correlation between BW and average FW was statistically significant, showing positive and higher value compared to other variables (0.626), as predicted, because the bunches have no rachis. Similar results were obtained for the genotypes tested by Donato et al. (2006a). The general trend found for this correlation is similar to that obtained by Lima Neto et al. (2003). Thus, one can infer that the characteristics bunch weight and average FW are directly correlated.

Similarly, the relationship between BW and FW was significant and positive (0.471) for the correlation between bunch weight and fruit number. In Donato et al. (2006a), the genotypes Calypso and PV 42-85 had

Table 4. Correlation coefficients of the relationship between variables measured at harvest and bunch weight.

Parameter	BW	LF	FW	NFB	SL	RW	NLH
BW	1.000	-	-	-	-	-	-
LF	0.340*	1.000	-	-	-	-	-
FW	0.626*	0.250*	1.000	-	-	-	-
NFB	0,471*	-0.255*	-0.580*	1.000	-	-	-
SL	0.060^{ns}	0.242*	0.265*	-0.249*	1.000	-	-
RW	0,576*	-0.031^{ns}	-0.216*	0.585*	0.201*	1.000	-
NLH	0.199*	0.112^{ns}	0.123^{ns}	-0.017^{ns}	0.086^{ns}	0124	1.000

BW: Bunch weight; LF: Length fruit (cm); FW: Average fruit weight (g); NFB: Number of fruits per bunch; SL: Stalk length (cm); RW: Rachis weight (g); NLH: Number of leaves at harvest; *: significant at 5% level of probability; ns, not significant at 5% probability.

negative correlation between BW and FW, but average FW had a positive correlation with BW, indicating that the cluster that has the greater weight may have lower number of fruits; nevertheless its unit size may be more. Lima Neto et al. (2003) found out that this correlation was positive and significant for almost all genotypes.

The relationship between BW and length of stem was not significant and positive (0.060), indicating that the weight of the bunch is independent of the length of stem. This result agrees with Donato et al. (2006a) who obtained a similar result for all genotypes tested, both the first and second cycles.

The weight of rachis showed a significant correlation which was positive and relatively high (0.576), denoting a general pattern of direct variation of the BW to the RW, a result expected since the clusters are composed of bunches (fruit) and rachis, and large clusters imply more rachis. For clusters with the same number of hands, the percentage of the rachis in the BW varied between 6.7 and 7.3% for Cavendish type of cultivars (Jaramillo, 1982).

A significant relationship between BW and number of leaves at harvest was found to be 0.199; this indicates that the BW varies directly with respect to the number of living leaves. However, this influence was not significant (low correlation); it did not affect the BW due to the fact that before the clusters are formed, the leaves have already fulfilled their role as source of food for the fruit. This is not an essential function, particularly because the plant (mother), in a commercial plantation, is cut down for the subsequent production of sucker.

With the harvest prediction model and the knowledge of correlation between variables and weight of the bunch, the producer can run an effective procurement plan for the prediction of productivity and harvest in terms of bank financing systems, since the study of the scientific prediction of bunch weight gives assurance of returns to lender.

Conclusion

The variables that correlated with the BW are average fruit weight, rachis weight, number of fruits per bunch, FL and number of leaves at harvest. The statistical model that expresses the production of the Tropical cultivar is formed by the characteristics: BW= -5,249 + 0,11NLH + 0,066NFB + 0,046FW + 0,183FL + 2,039RW -0,011LS. The vegetative characters are not good indicators for the prediction of BW.

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