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Genetic Resources and Crop Evolution **46:** 455–460, 1999.

In situ evaluation of fruit yield and estimation of repeatability coefficient for major fruit traits of umbu tree [*Spondias tuberosa* (Anacardiaceae)] in the semi-arid region of Brazil

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Received 20 August 1998; accepted in revised form 15 December 1998

Key words: in situ evaluation of fruit tree, repeatability coefficient, *Spondias tuberosa*, yield components

Abstract

The umbu tree (*Spondias tuberosa*) is a xerophytic woody species endemic to the northeast of Brazil. The present work reports a three-year *in situ* evaluation of major yield components in a random set of trees in Petrolina city, Pernambuco State, Brazil and the application of repeatability coefficient in the context of genetic resources utilization. Five traits were assessed: total fruit yield per plant (FY); total number of fruits per plant (NF); average fruit weight (FW); average pulp weight (PW) and average fruit diameter (FD). The values observed for FY ranged from 4.2–184 kg with mean of 61.5 kg. The values for NF ranged from 257 to 12,981 fruits/tree with mean 3,993 fruits. For FW, the range was from 10.82–23.36 g with mean of 16.03 g. The values for PW ranged from 7 to 17 g with mean of 11.2 g, while FD values varied from 2.5 to 3.5 cm with mean of 3.0 cm. Six methods were employed to estimate repeatability coefficient (r) for all parameters. The *r* ranged from 0.68–0.76 for NF; 0.87–0.89 for FW; 0.65–0.75 for FY; 0.64–0.78 for PW and 0.70–0.84 for FD. Narrower ranges across methods were observed to *r*-values greater than 0.80, as observed for FW and FD. Three to four years of measurements will be necessary for FY, NF, and PW and one year for FW to obtain a precision of 90% to provide a reliable identification of individuals for *in situ* or *ex situ* conservation.

Introduction

The umbu tree, *Spondias tuberosa* A. Camara (Anacardiaceae), is a xerophytic woody species with endemic geographic distribution in the semi-arid tropical vegetation (caatinga) of Brazil (Prado & Gibbs, 1993). The high tolerance of this species to drought is conferred by a specialized root structure (xylopodium) which plays a key role in long-term water storage. The tree has edible fruits with very peculiar aroma, which are suitable for both fresh market and the processing industry. For these reasons, umbu tree is considered to be an ideal plant species for cultivation in an environment with reduced rainfall or a lacking supply of irrigation water, such as that observed in some tropical semi-arid regions of Brazil.

Improvement of *S. tuberosa* via conventional breeding is underway (Santos et al. 1996) but the amount of basic information about yield potential and stability of yield components in the native habitat is still insufficient. Previous reports based upon a single fruit harvesting indicated an average yield of about 300 kg of fruits per plant per year (Duque, 1980; Brito et al., 1996). In addition, a large fluctuation in total fruit yield across years has been reported in a non-systematic survey (Queiroz et al., 1993).

Fruit yield in woody plants is a metric trait whose phenotypic expression in individual trees may vary between seasons as a response to changes in the environment or due to measurement error variance. For traits evaluated more than one time in the same individual, such as fruit production, it is possible to estimate a repeatability coefficient. This coefficient is based on repeated measurements of one trait on the same '*n*' individuals in order to estimate the capacity that they have to repeat the character expression

(Lush, 1945). The repeatability coefficient provides an unbiased estimation of the upper bound value of broad-sense heritability of a given quantitative trait (Falconer & Mackey, 1996) and can be used to estimate the minimun number of assessments necessary for an accurate trait evaluation (Vasconcelos et al., 1985).

The present work reports a three-year *in situ* evaluation of five traits and the estimate of the repeatability coefficient (r) in a set of native umbu trees under natural conditions. In addition, some considerations about six distinct methods for estimation of r for this uncultivated species are presented.

Material and methods

Plant material and trait assessment

Sixteen umbu trees at the mature/productive stage (climax age) were randomly selected within the area of the experimental field of the Center for Agricultural Research of the Brazilian Semi-Arid Tropic (CPATSA)–EMBRAPA, Petrolina, Pernambuco State, Brazil. Five traits were assessed during three consecutive seasons (1995–97): fruit yield in kg per plant (FY); total number of fruits per plant (NF); average fruit weight in grams (FW); flesh pulp weight in gram (PW) and average diameter (cm) of the fruits (FD). NF, FW, and FY were evaluated with fully ripe fruits at 2 day intervals during the production time (February through April). PW and FD were assessed using 50 fruits of five harvesting during the production period.

Repeatability coefficient estimation

Estimates of the coefficient of repeatability (r) were obtained by using six distinct methods (for complete review see Rutledge, 1972; Mansour et al., 1981; Cruz & Regazzi, 1994). All estimators are presented in Table 2:

1. ANOVA with error confounded (method # 1): analysis of variance with temporary effect confounded with the error. The coefficient r was estimated based upon variance components associated with the error among and within trees (Abeywardena, 1972; Cruz & Regazzi, 1994). There are only two source of variation: trees and error;
2. ANOVA with error removed (method #2): variance analysis estimator with the temporary effect removed from the error. The r was estimated from variance components associated with tree and error sources (Abeywardena, 1972; Cruz & Regazzi, 1994). There are three sources of variation: trees, years and error;
3. Principal component – covariance matrix (method #3): the estimator was based upon principal components extracted from sample covariance matrix (Mansour et al., 1981);
4. Principal components – correlation matrix (method #4): the estimator was based upon principal components extracted from sample correlation matrix (Abeywardena, 1972; Rutledge, 1972; Mansour et al., 1981);
5. Structural estimator – correlation matrix (method #5): it is the structural estimator from sample correlation matrix using eigenvector corresponding to the largest characteristic root (Mansour et al., 1981);
6. Structural estimator – covariance matrix (method #6): it is the structural estimator from sample covariance and variance matrix using eigenvector corresponding to the largest characteristic root (Mansour et al., 1981).

The r-value estimations were made using the software Genes (Cruz, 1997). The number of years for an accurate trait measurement with 90% of probability was obtained by the equation $n = [0.90\,(1 - r)]/\,[(1 - 0.90)\,r]$, where, n = number of years for a determination (R^2) or prediction of 90% and r = repeatability coefficient.

Results and discussion

Yield component estimation

The mean values observed for FY ranged from 4.2 to 184 kg with a mean of 61.5 kg (Table 1). These values are smaller than reported by Duque (1980) and Brito et al. (1996). However, the yield production in the present work was obtained harvesting trees at two day intervals during the production season, while Duque (1980) and Brito et al. (1996) estimated yield production multiplying by two the total weight of fruits harvested at one time and in different stages of maturation. Overall, the individual trees did not show large variation across years for FY. The ranking based on FY was very stable across years suggesting that there are trees with great capacity to produce fruits in contrast with others that show small capacity to produce fruit (Table 1). Therefore, in disagreement with a previous report (Queiroz et al., 1993), the fluctuation of production fruits among years in the same tree does

Table 1. Values and means of some traits and yield production evaluated in sixteen umbu trees of spontaneous occurrence in Petrolina, Pernambuco State, Brazil, in the years of 1995–1997

Tree	Traits[1]																			
	NF				FW				FY				PW				FD			
	1995	1996	1997	Mean	1995	1996	1997	Mean	1995	1996	1997	Mean	1995	1996	1997	Mean	1995	1996	1997	Mean
1	1087	786	2336	1403	23.7	25.1	21.4	23.4	25.8	19.7	49.9	31.8	14.6	19.9	16.4	17.0	3.4	3.7	3.6	3.5
2	1514	4643	1013	2390	14.9	14.3	14.6	14.6	22.6	66.4	14.8	34.6	11.2	10.2	9.1	11.5	2.8	2.7	2.9	2.8
3	509	183	79	257	16.1	16.7	16.0	16.2	8.2	3.1	1.3	4.2	13.0	14.3	11.2	13.6	3.0	3.1	3.1	3.1
4	1655	5576	3311	3514	19.0	19.3	16.5	18.3	31.5	107.8	54.7	64.7	14.0	14.3	11.5	13.3	3.1	3.1	3.4	3.2
5	1010	4418	4152	3193	19.1	21.9	20.5	20.5	19.3	96.8	85.3	67.1	11.7	16.4	16.3	14.8	3.2	3.2	3.4	3.3
6	3860	14728	9819	9469	16.7	16.0	15.5	16.0	64.3	235.0	151.7	150.3	10.6	12.6	11.0	11.4	2.9	3.1	3.2	3.1
7	10069	8014	14959	11014	15.7	18.4	16.5	16.8	157.6	147.1	247.2	184.0	11.0	14.2	12.4	12.5	3.0	3.1	3.5	3.2
8	2632	5814	1988	3478	17.6	16.6	17.9	17.3	46.3	96.2	35.6	59.4	11.3	10.2	12.1	11.2	3.1	2.8	2.9	2.9
9	2476	6	116	866	10.1	12.6	10.6	11.1	24.9	0.1	1.2	8.7	5.1	8.7	7.3	7.0	2.4	2.6	2.9	2.6
10	2138	2315	3618	2690	14.4	15.2	16.5	15.4	30.8	35.2	59.6	41.9	9.6	12.1	11.1	10.9	2.8	2.9	3.0	2.9
11	1191	847	2231	1423	10.7	11.4	11.9	11.3	12.7	9.6	26.6	16.3	7.2	5.7	8.6	7.2	2.5	2.4	2.8	2.5
12	3376	308	2103	1929	13.0	15.2	13.8	14.0	43.7	4.7	30.3	26.2	9.3	7.9	8.6	8.6	2.8	2.5	2.9	2.7
13	5973	3988	5486	5149	15.9	15.6	17.5	16.4	95.2	62.3	94.2	83.9	6.4	8.5	11.8	8.9	2.8	2.7	3.3	2.9
14	8588	18405	11949	12981	10.9	10.5	11.0	10.8	93.8	193.0	131.8	139.5	6.2	7.8	7.7	7.2	2.6	2.4	2.6	2.5
15	138	3267	496	1300	18.4	18.4	15.1	17.3	2.5	60.1	7.5	23.4	11.2	12.5	10.7	11.5	3.1	2.9	3.2	3.1
16	3615	1843	3022	2827	14.7	17.8	18.7	17.1	53.0	32.9	56.4	47.4	8.8	14.4	13.3	12.2	2.8	3.0	2.9	2.9
Mean	3114	4696	4167	3993	15.7	16.7	15.9	16.0	45.8	73.1	65.5	61.5	10.1	12.3	11.2	11.2	2.9	2.9	3.1	3.0

[1] FY = fruit yield (kg) per plant; NF = total number of fruits per plant; FW = average fruit weight in gram; PW = flesh (pulp) weight in gram and FD = average diameter (cm) of the fruits.

Table 2. Repeatability coefficients (r), determination coefficients (R^2)[1] and number of years (n) for a determination of 90% estimated in sixteen umbu trees of spontaneous occurrence in Petrolina, Pernambuco State, Brazil, evaluated in the years of 1995–1997

Method of estimation	Estimator	Traits[2]														
		NF			FW			FY			PW			FD		
		r	R^2	n	r	R^2	n	r	R^2	n	r	R^2	n	r	R^2	n
1. ANOVA with error confounded[3]	$\hat{\rho} = \hat{\sigma}^2_G/(\hat{\sigma}^2 + \hat{\sigma}^2_G)$	0.68	86.5	4	0.87	95.3	1	0.65	84.8	5	0.64	84.1	5	0.69	86.9	4
2. ANOVA with error removed[4]	$\hat{\rho} = \hat{\sigma}^2_G/(\hat{\sigma}^2 + \hat{\sigma}^2_G)$	0.69	87.2	4	0.88	95.7	1	0.68	86.3	4	0.72	88.3	4	0.81	92.7	2
3. Principal components - covariance matrix	$\hat{\rho} = \hat{\lambda}_1 - \hat{\sigma}^2_{y})/[\hat{\sigma}^2_{y}(n-1)]$	0.78	91.4	3	0.89	96.2	1	0.75	90.1	3	0.78	91.4	3	0.84	93.8	2
4. Principal components - correlation matrix	$\hat{\rho} = (\hat{\lambda} - 1)/(n-1)$	0.76	90.4	3	0.89	95.9	1	0.73	89.2	3	0.74	89.4	3	0.82	93.3	2
5. Structural estimator - correlation matrix	$\hat{\rho} = (\alpha' \hat{R} \alpha - 1)/(n-1)$	0.76	90.3	3	0.89	95.9	1	0.73	89.0	3	0.74	89.4	3	0.82	93.2	2
6. Structural estimator - covariance matrix	$\hat{\rho} = (\alpha' \hat{\Gamma} \alpha - \hat{\sigma}^2_{y})/\hat{\sigma}^2_{y}(n-1)$	0.69	87.2	4	0.88	95.7	1	0.68	86.3	4	0.72	88.3	4	0.81	92.7	2

[1] $R^2 = [n * r]/[1 + r(n-1)]$, where n is the number of years of evaluation.
[2] FY = fruit yield (kg) per plant; NE = total number of fruits per plant; FW = average fruit weight in gram; PW = flesh (pulp) weight in gram and FD = average diameter (cm) of the fruits.
[3] Source of variation: trees and error.
[4] Source of variation: trees, years and error.

not seem an important phenomenon in umbu tree of spontaneous occurrence.

The mean values for NF ranged from 257 to 12,981 fruits/tree, with a mean of 3,993 fruits. NF has been considered as the most important trait for use in indirect selection of more productive umbu trees (Santos & Nascimento, 1997). Range of 10.82 to 23.36 g was observed for FW, with a mean of 16.0 g. The values for PW ranged from 7.03–17.0 g, with the mean of 11.2 g, while FD mean values varied from 2.5 to 3.5 cm, with a mean of 3.0 cm (Table 1). Overall means of NF, FW, PW and FD are very similar to those reported by Santos (1997) in a large study conducted with 340 umbu trees throughout the Brazilian semi-arid region.

Repeatability coefficient estimation

Six methods were employed to estimate the repeatability coefficient (r) for all five-yield parameters using the three-year data set. Identical estimates were obtained with methods #2 and #6. These results are in accordance with Mansour et al. (1981) who by using straightforward algebra demonstrated that both estimators are, in fact, identical. Similar values for all traits were also consistently observed with methods #4 and #5 while the smallest and the largest estimate were obtained with method #1 and #3, respectively (Table 2). The same situation was observed with the determination coefficient (R^2) because this coefficient is calculated based upon r-values.

According to the method employed, the r-values ranged from 0.68 to 0.78 for NF; 0.87–0.89 for FW; 0.65–0.75 for FY; 0.64–0.75 for PW and 0.69–0.84 for FD (Table 2). The most concordant r-values were observed for PW while a wider range of r-values was observed in traits NF, FW and FY. It can be observed that when the r-values were greater than 0.80, the methods showed generally closer results (Table 2).

The results indicated that for obtaining a confidence of 90% in the yield measurements, 3–4 years of evaluation would be necessary for FY, NF, PW and PW, whereas only one year would be necessary for FW (Table 2). Hence, once the repeatability value of a given trait is known, it is possible to reduce the successive evaluation and the likelihood that clonally propagated trees will express the desired trait is high. In cacao, it was estimated that it is possible to select genotypes in pre-climax age on the basis of only two years of successive harvesting (Dias & Kageyama, 1998).

According to Mansour et al. (1981) the structural estimator from sample the correlation matrix (method #5) appears to be the best when compared to all other methods applied in the present study, with the exception of method #1. Abeywardena (1972) found that principal components estimator gives consistent estimates in five simulated situations than methods using ANOVA (methods #1 and 2). On the other hand, according to Cruz & Regazzi (1994), method #1 is more suitable for a situation where the measurements are done in distinct experimental conditions for all plants. The methods of principal components (Abeywardena, 1972; Rutledge, 1974) (#3 & 4) give consistently accurate results when the individuals are subject to irregular changes such as fluctuation due to the weather or regular changes such as biennial effects or monotonic changes such as degeneration due to senility (Abeywardena, 1972). In the present study both situations occurred with soil conditions not the same for all individuals and oscillations in rainfall. More studies are necessary to determinate which method is more suitable and gives more accurate estimates for uncultivated species, such as umbu tree, mainly when the r-values are less than 0.80.

The coefficient r is an upper limit of relation of genetic and phenotypic variance (Falconer & Mackey, 1996). A practical consequence, for the plant breeding standpoint, associated with large r-value is the strong indication that a considerable amount of the phenotypic variance of these traits can be the result of genetic variance, i.e. genetic variance surpasses the environmental variance (Lynch & Walsh, 1998).

The r-value estimate has some practical implications on both effective collection of germplasm and subsequent characterization and evaluation of genetic resources of *S. tuberosa*. The results indicated that one year is enough to obtain a reliable identification of plants with large average fruit weight (FW). For that specific trait plants can be identified with either single year *in situ* evaluation or by gathering information with farmers and local inhabitants of rural areas living nearby umbu tree. For fruit yield per plant (FY), total number of fruits per plant (NF) and flesh pulp weight (PW) 3–4 years of measurement would be necessary to have a reliable identification of potentially more productive individuals.

Acknowledgments

The author is grateful to L.S. Boiteux (CNPH-EMBRAPA, Brazil) for his comments and suggestions on the original manuscript.

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