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# Repeatability and number of harvests required for selection in coconut hybrid varieties

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**In the breeding of perennial plant species, the coefficient of repeatability is an important parameter because it allows for effective early selection of superior genotypes, thus saving time and cost. The objective of this study was to determine the minimum number of years required for observation to identify superior genotypes of coconut with a high degree of accuracy. Four hybrid varieties of coconut were evaluated in a randomized complete block design with two replications each year for four years (2009-2012) in Benin City, Edo State, Nigeria. The repeatability coefficient was calculated using principal components based on correlation and covariance matrices, and the minimum number of years required for observation to identify superior genotypes was estimated. The repeatability coefficient ranged from 0.63 to 0.90, while the coefficient of determination ranged from 0.87 to 0.97 for the two methods of principal component analysis for yield and its components. For each of the traits studied, the repeatability coefficient estimated by principal components based on correlation matrix was lower than the value obtained by the principal components based on the covariance matrix. Estimates of the number of years required for observation to identify superior genotypes based on correlation and covariance matrix of the principal component analysis ranged from 2-58 years at a pre-established reliability coefficient of 80-99%. Results from the simulation models showed that an increase in number of years of evaluation beyond four did not appreciably increase the precision for the selection of superior genotypes ($R^2$> 85%) for each of the traits evaluated. Based on repeatability index, four-year yield records are adequate for the identification of superior genotypes with a high degree of accuracy.**

**Key words:** Repeatability, hybrid varieties, principal components, reliability coefficient.

## INTRODUCTION

Coconut (*Cocos nucifera* L.) is the most economic crop along the coastal belt of West Africa. Its cultivation, processing and marketing offer employment opportunities and serve as the main source of income for many people (Eden and Ofori, 1995). It is popularly known as 'tree of life' because of its diverse economic uses and importance in sustaining the life of the people who grow them. It is classified as a "functional food" because it provides many

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health benefits beyond its nutritional content (Pamplona-Roger, 2007). There are two major varieties, the tall and dwarf. A third, the hybrid variety, was developed from the original two. These varieties are well adapted to the tropics (Edward and Craig, 2006).

The coefficient of repeatability is an important parameter in the breeding of perennial plant species because it allows effective early selection of superior plants and/or progenies (Dias and Kageyama, 1998). Repeatability describes the correlation between successive measurements of a trait, and can serve as a basis for the estimation of the likelihood that the initial superiority or inferiority of a genotype will remain over time and/or space. It expresses the proportion of the total variance explained by the variations caused by the genotype and the permanent alterations attributed to the common environment (Cruz and Regazzi, 1997). When a trait of the same plant is measured 'n' times, the mean of these 'n' observations is an unbiased estimator of the genotypic value for this trait (Falconer, 1989). Phenotypic variance for a trait can be split into two components. One is the temporal variation, reflecting differences between successive measurements of each plant and has a purely environmental origin. The other, which is partly due to environmental and partly to genotypic variation, is useful in describing differences among plants. The environmental conditions under which plants are grown, the nature of the trait and genetic properties of a population are factors that affect the estimate of repeatability. A high repeatability value indicates the possibility of early selection of superior genotypes or discrimination among genotypes based on a relatively small number of evaluations (Cornacchia et al., 1995). Consequently, information on repeatability allows an efficient use of resources and time in the evaluation phase.

Two most widely used methods for the estimation of repeatability coefficients are the variance analysis and the principal component methods. The principal component method, in turn, is used to estimate repeatability by two methods viz. correlations and covariance. The Nigerian Institute for Oil Palm Research (NIFOR) has exotic and local coconut hybrid varieties in her germplasm. However, these hybrid varieties have not been released to farmers in Edo State because the yield patterns have not been determined. The objective of this study was to estimate the repeatability coefficient for yield and its components in coconut by two principal component methods, towards obtaining information on the minimum number of evaluations for effective selection and discrimination among genotypes.

## MATERIALS AND METHODS

### Location and experimental site

The study was carried out in one of the research fields at the Headquarters of the Nigerian Institute for Oil Palm Research (NIFOR), Benin City (Latitude 6°33'N, Longitude 5°37'E, 183 m above mean sea level), Edo State, Nigeria. Benin City is in the tropical rainforest.

### Experimental materials

The experimental material for the present study comprised four hybrid varieties of coconut viz. Malayan Yellow Dwarf x Vanuatu Tall (MYD x VTT), Sri-Lanka Green Dwarf x Vanuatu Tall (SGD x VTT), Malayan Green Dwarf x West Africa Tall (MGD x WAT), and Malayan Yellow Dwarf x West Africa Tall (MYD x WAT).The first two originated from Ghana while the remaining two were developed at NIFOR, Nigeria.

### Experimental layout and planting

The experimental design was randomized complete block with two replications. Each genotype in each replicate was grown in a plot of two rows with eight palms per plot. Spacing was 7.5 x 7.5 m, giving a density of 178 plants per hectare. One-year old palms were transplanted to the field on 5 August, 2003 in a 1.0 $m^3$ hole (Nair et al., 2003) with a double layer of coconut husk filled with green manure in the first 33.3 cm depth. Top soil was used to fill the second 33.3 cm depth. The last 33.3 cm depth was left empty to hold water.

### Data collection

Data were collected for four consecutive years (from 2009-2012). Data were collected on the yield characters as follows:

#### *Nut load palm$^{-1}$ year$^{-1}$*

Each palm was inspected every week for mature bunch. Mature bunches present were harvested and the fruits were counted and numbered. The nut load per year for all palms were added and divided by number of palms per plot to obtain nut load palm$^{-1}$ year$^{-1}$.

#### *Weight of whole nut palm$^{-1}$ year$^{-1}$(kg)*

Five matured nuts were randomly sampled from the nuts produced by each palm. Each of the nuts was weighed (Mathur et al., 2008). The average weight of the fruits sampled from each palm was multiplied by nut load palm$^{-1}$ year$^{-1}$ to obtain weight of whole nut palm $^{-1}$ year$^{-1}$.

#### *Copra yield palm$^{-1}$ year$^{-1}$(kg)*

Each nut was broken, the water removed, and the nut reweighed. The meat (white flesh) was then removed, weighed, and placed in a kiln at 70°C. After 18 h, when the moisture content was at an average of 6%, the copra weight was recorded. The copra weight per nut was multiplied by the nut load per palm per year to obtain the copra yield per palm per year. Copra yield per hectare per year was obtained by multiplying the copra yield per palm per year by the number of plants per hectare (Dare et al., 2010).

### Estimation of repeatability and evaluation period

Estimate of the repeatability coefficient was obtained by the analysis of the main components proposed by Abeywardena (1972). The repeatability coefficient was calculated using principal

**Table 1.** Four years estimates of the coefficients of repeatability (r) and of determination ($R^2$) of yield components of coconut considering two methods of principal component analysis.

| Method | r | $R^2$ |
|---|---|---|
| Nut yield (nuts $palm^{-1}year^{-1}$) | | |
| Principal components based on the correlation matrix | 0.691 | 0.899 |
| Principal components based on the covariance matrix | 0.757 | 0.926 |
| Whole nut weight (kg $palm^{-1}year^{-1}$) | | |
| Principal components based on the correlation matrix | 0.686 | 0.897 |
| Principal components based on the covariance matrix | 0.859 | 0.961 |
| Copra weight (kg $palm^{-1}year^{-1}$) | | |
| Principal components based on the correlation matrix | 0.634 | 0.874 |
| Principal components based on the covariance matrix | 0.897 | 0.972 |
| Copra yield (t $ha^{-1}$) | | |
| Principal components based on the correlation matrix | 0.636 | 0.875 |
| Principal components based on the covariance matrix | 0.897 | 0.972 |

components based on correlation and covariance matrices. The Eigen values and normalized Eigenvectors were determined. A latent vector (1, 1, 1, 1…) which gives the same sign and nearly equal weights to all the elements in the vector (called size vector) was obtained. The Eigen vector, which elements present the same sign and similar magnitudes is the one that expresses the tendency of the genotypes to maintain their relative positions in the various time periods (Cruz and Regazzi, 1997; Abeywardena, 1972), and the proportion of the total variance, accounted for by this vector is a measure of the repeatability coefficient. This analysis was performed using the PROC PRINCOMP procedure of SAS (SAS Institute, Inc. 2002).

The minimum number of years of evaluation required to express the genotypic potential of the evaluated hybrids based on the pre-established coefficient of determination ($R_p^2$: 0.80; 0.85; 0.90; 0.95; 0.99), was calculated by the following formula:

$$N_0 = Rp^2\ (1 - r)/\ (1 - R_p^2)\ r$$

where, $N_0$ = minimum number of years required for phenotypic selection among the genotypes; $R_p^2$ = pre-established coefficient of determination; r = repeatability coefficient.

The estimated coefficient of determination ($R_e^2$) was computed as (Júlio et al., 2008):

$$R_e^2 = \frac{N\,x\,r}{1 + r(N-1)}$$

where, N= number of years of evaluation, and r = repeatability coefficient. The number of necessary yearly harvests (n) to obtain different coefficients of determination for the two estimation methods (based on correlation and covariance matrix of the principal component analysis) were simulated for the various traits evaluated (Aymbiré et al., 2004).

## RESULTS

### Repeatability and evaluation period

The repeatability coefficients (r) and respective coefficients of determination ($R^2$) of the yield components of coconut estimated over four years, and from two methods are given in Table 1. Repeatability coefficient (r) by principal components based on correlation matrix was 0.69 for nut yield, 0.69 for whole nut weight, 0.63 for copra weight and 0.64 for copra yield, while repeatability coefficient estimated by the principal components method based on covariance matrix was 0.76 for nut yield, 0.86 for whole nut weight, 0.90 for copra weight and 0.90 for copra yield.

The coefficients of determination for nut yield were 0.90 and 0.93 from correlation and covariance matrix methods, while for whole nut weight the coefficients of determination were 0.90 and 0.96, respectively. For copra weight, the coefficients of determination were 0.87 and 0.97 from the correlation and covariance matrix methods, and 0.90 and 0.97, respectively for copra yield. For all traits considered, the values of the repeatability coefficient estimated by principal components based on correlation matrix were lower than the values obtained by the principal components based on the covariance matrix.

Estimates of the number of years required for an accurate phenotypic selection of superior hybrid varieties for the evaluated traits based on five pre-established coefficients of determination for the two methods are shown in Table 2.

The number of years based on correlation matrix at a pre-established reliability coefficient of 80, 85, 90, 95 and 99% were 2,3,5,9, 45 years for nut yield; 2,3,5,9,46 years for whole nut weight; 3,4,6,11,58 years for copra weight; 3,4,6,11,57 years for copra yield, while that of the method of principal component analysis based on covariance matrix were 2,2,3,7,32 years; 1,1,2,4,17 years; 1,1,2,3,12 years;1,1,2,3,12 years, respectively.

Figures 1 to 4 show the simulation of the number of necessary harvests (n) to obtain different coefficients of determination for two estimation methods (correlation and covariance matrix of the principal component analysis)

**Table 2.** Number of years (n), in two methods for estimating the repeatability coefficient associated with the different pre-established coefficients of determination ($R^2$) required for the selection of genotypes of coconut

| | Nut yield palm $yr^{-1}$ | | Whole nut weight kg $palm^{-1}$ $yr^{-1}$ | | Copra weight kg $palm^{-1}$ $yr^{-1}$ | | Copra yield t $ha^{-1}$ | |
|---|---|---|---|---|---|---|---|---|
| **Method** | **n** | **($R^2$)** | **n** | **($R^2$)** | **n** | **($R^2$)** | **n** | **($R^2$)** |
| Principal Components based on the correlation matrix | 2 | 80 | 2 | 80 | 3 | 80 | 3 | 80 |
| Principal components based on the covariance matrix | 2 | 80 | 1 | 80 | 1 | 80 | 1 | 80 |
| Principal Components based on the correlation matrix | 3 | 85 | 3 | 85 | 4 | 85 | 4 | 85 |
| Principal components based on the covariance matrix | 2 | 85 | 1 | 85 | 1 | 85 | 1 | 85 |
| Principal Components based on the correlation matrix | 5 | 90 | 5 | 90 | 6 | 90 | 6 | 90 |
| Principal components based on the covariance matrix | 3 | 90 | 2 | 90 | 2 | 90 | 2 | 90 |
| Principal Components based on the correlation matrix | 9 | 95 | 9 | 95 | 11 | 95 | 11 | 95 |
| Principal components based on the covariance matrix | 7 | 95 | 4 | 95 | 3 | 95 | 3 | 95 |
| Principal Components based on the correlation matrix | 45 | 99 | 46 | 99 | 58 | 99 | 57 | 99 |
| Principal Components based on the covariance matrix | 32 | 99 | 17 | 99 | 12 | 99 | 12 | 99 |

for the various traits evaluated. In the simulation models, it was observed that an increased 'n' (number of years of evaluation) beyond four years did not appreciably increase the precision for the selection of superior genotype for each of the traits evaluated as indicated by the $R^2$ value.

## DISCUSSION

The identification of superior genotypes depends on efficient germplasm evaluation that allows for genetic differences and discrimination among genotypes (Antonio et al., 2002). Estimates of coefficients of repeatability and determination are useful for determining the lowest number of successive harvests required to assess the genetic potential of the evaluated genotypes with desired accuracy at minimum cost and labour (Cruz et al., 2004; Didner et al., 2008). The magnitude of repeatability coefficient (0.636 - 0.897) and coefficient of determination (0.874 – 0.972) obtained in this study from the two methods of principal component analysis were relatively high for all traits considered. These values integrate the biennial bearing nature of the coconut palm for which yield is high in certain year (on-phase), low in the following year (off-phase), high again in the next year (on-phase), and so on (Abeywardena, 1972).They also indicate that the mathematical model used provided a satisfactory fit to the data set (Cavalcante et al., 2012). Estimates of repeatability coefficient greater than 0.5, and coefficient of determination greater than 80% are considered adequate (Shimoya et al., 2002). Julio et al. (2008) reported that the high number of years required for coefficients of determination values over 90% would increase cost, thus reducing efficiency.

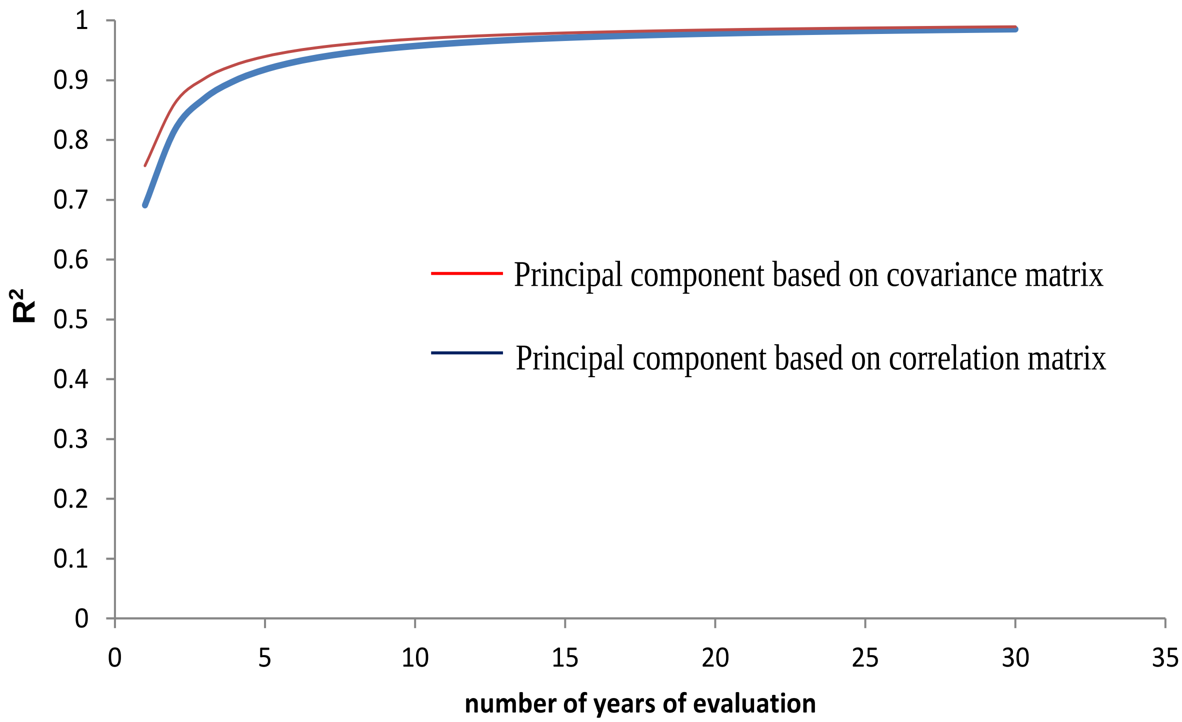


**Figure 1.** Comparison of two multivariate models for the estimation of repeatability for determining precision level and minimum number of years of evaluation for nut load.

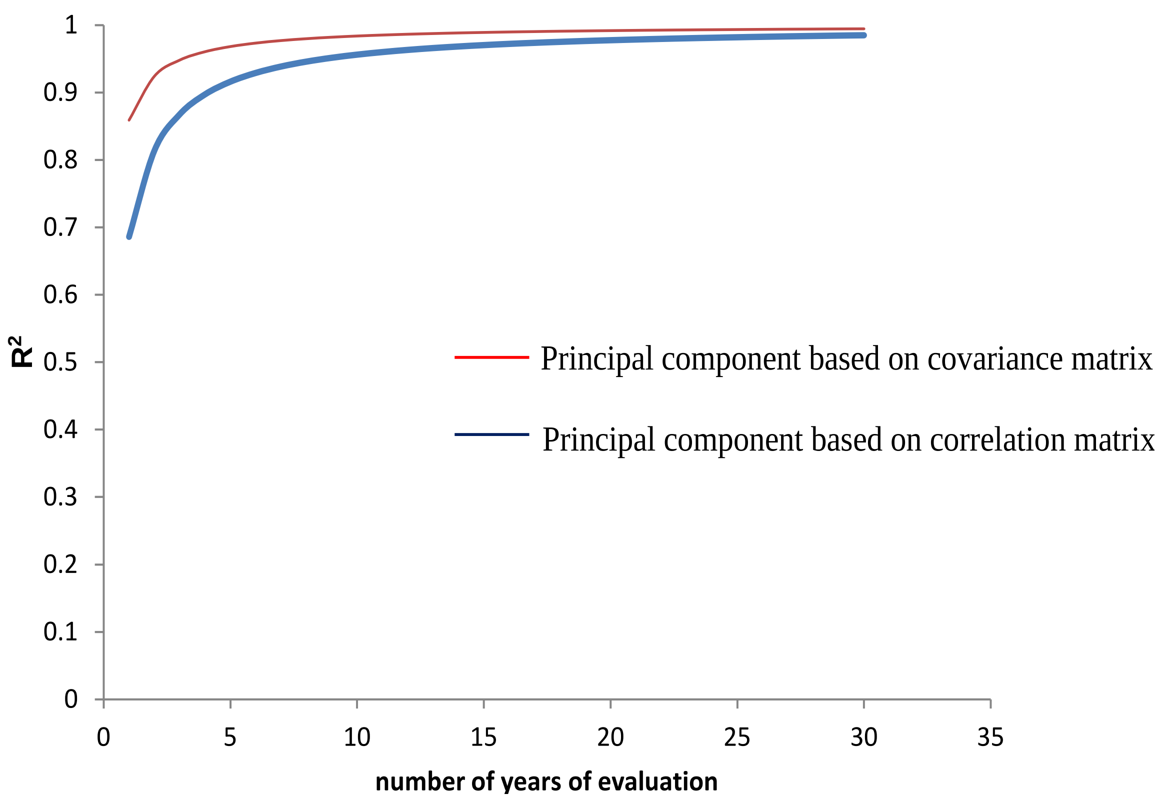


**Figure 2.** Comparison of two multivariate models for the estimation of repeatability for determining precision level and minimum number of years of evaluation for whole nut weight.

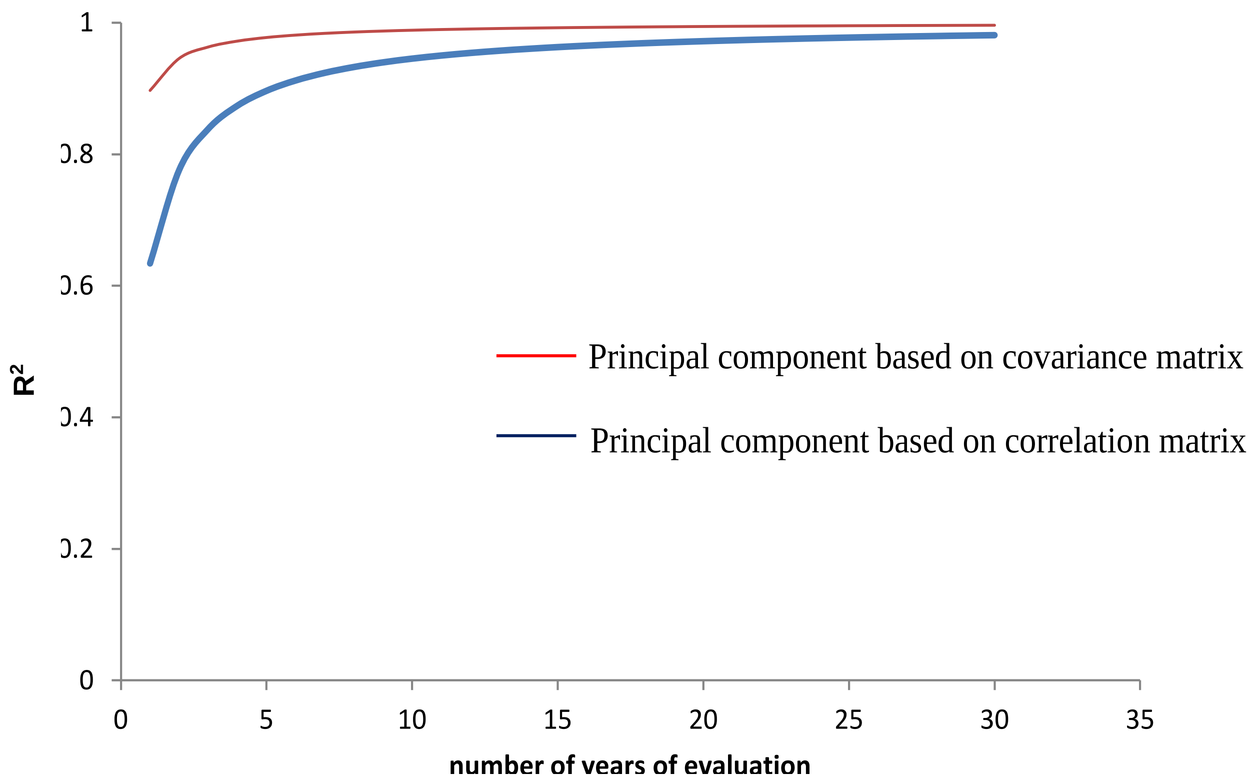


**Figure 3.** Comparison of two multivariate models for the estimation of repeatability for determining precision level and minimum number of years of evaluation for copra weight.

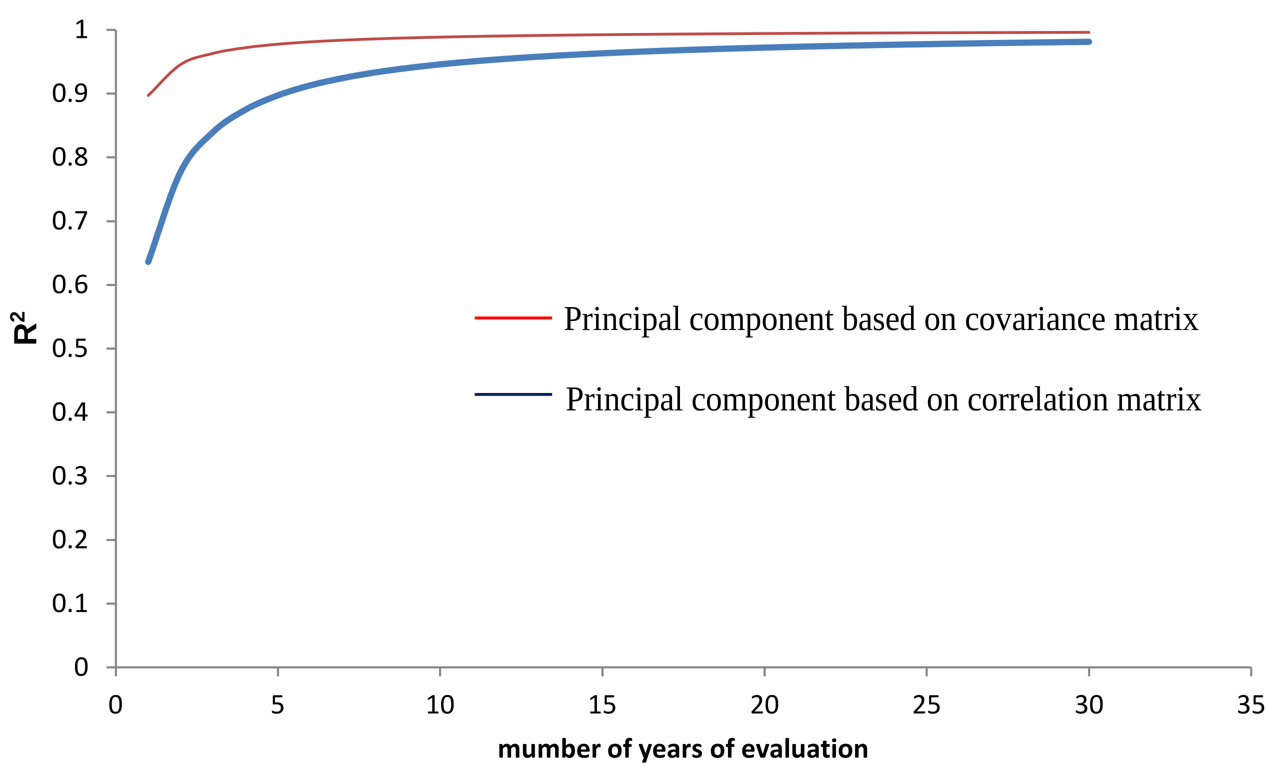


**Figure 4.** Comparison of two multivariate models for the estimation of repeatability for determining precision level and minimum number of years of evaluation for copra yield.

Abeywardena (1972) demonstrated that the most adequate estimate of the repeatability coefficient, especially when the genotypes of perennial species present cyclic performance throughout the evaluations in relation to the studied trait, is that obtained through the method of principal components. The biennial yield cycle of perennial crops is mainly due to climatic adversities, such as drought or frost and may vary in form and intensity among the evaluated genotypes (Cruz and Regazzi, 1997; Aymbiré et al., 2004; Júlio et al., 2008). In the case of the coconut palm, a large number of inflorescences usually emerge during the rainy season, resulting in higher fruit setting. In this first year of production, the yield is therefore normally high. However, new inflorescences appear in lower numbers during the dry season, thus increasing the probability of a low yield in the following year through a delay in the emergence of the spadix or its abortion. Since the floral primordia are initiated 12 months before the spadix emerges, the number of fruits is correlated to the growing conditions (weather and nutrition) 12 months prior to emergence (Edward and Craig, 2006). From pollination; it takes about 12 months for the fruit to mature. The first mature fruits are produced 5-6 years from planting. Fruits are produced throughout the year, but where rainfall is seasonal more fruits are produced in some months than others. These cyclic variations in coconut justify the use of principal component analysis for a better estimate of repeatability.

In the present study, the repeatability varied with the yield traits. Cruz et al. (2004) reported that repeatability estimates vary depending on the nature of the trait evaluated, the genetic properties of the population and the environmental conditions under which the plants are grown. The estimates of repeatability and coefficient of determination obtained by the method of principal component analysis based on covariance matrix for the yield components showed greater accuracy than the estimates by the method of principal component based on correlation matrix. Other authors (Cornacchia et al., 1995; Júlio et al., 2008; Cargnelutti et al., 2004; Cavalcante et al., 2012; Souza et al., 2010; Matsuo et al., 2012) have also observed greater accuracy in estimates of repeatability based on covariance matrix.

The values of the coefficient of determination ($R^2$) obtained in this study for all the characters evaluated using both methods were over the threshold of 80% recommended by Resende (2002), and can thus be considered adequate for the selection of superior genotypes.

With respect to the evaluation period and considering all the traits, the covariance matrix method of principal component analysis at a coefficient of determination of 85% ($R^2$=85%) is considered the best.

In the present study, 2-4 years data are required for selection depending on the method used and the yield trait. Results of our study indicate that irrespective of the method used and considering yield and all yield components, four years of evaluation is optimal, and an increase in evaluation period beyond four years with its associated increased cost and loss of time would not result in an appreciable increase in precision of selection for yield in coconut. This number of evaluation cycles will also provide information on genotype x environment interactions. Four years was reported as the time required for effective selection of oil palm progenies (Didner et al., 2008). Bastidas (1989) also reported four years as the minimum evaluation time required for selection of parent plants in oil palm. In robusta coffee (*Coffea canephora*), a perennial crop, Aymbiré et al. (2004) and Fonseca et al. (2004) also reported that four successive harvests are sufficient for the selection of robusta coffee genotypes with respect to yield.

The low number of evaluation cycles determined as necessary for effective selection in this study can be attributed to the close fit of the multivariate model with the dataset. The high $R^2$ values obtained for both methods indicate that any of the two methods of PCA evaluated in this study is suitable for a reliable estimate of repeatability. The PCA approach is more stable and efficient because it helps to highlight, measure, and eliminate certain latent aspects of variation. This method is credited with the ability to disentangle the variance components from any periodic influence and other seasonal variations that may occur in perennial crops, and removes this component from the error variance, thus estimating the repeatability index accurately (Abeywardena, 1962).

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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