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Fruit biometry and physiological quality of *Veitchia merrilli* (Becc) H. E. Moore palm in relation to fruit maturation stage

Biometria do fruto e qualidade fisiológica da palmeira *Veitchia merrilli* (Becc) H. E. Moore de acordo com o estágio de maturação do fruto

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ABSTRACT

Veitchia merrilli (Becc) H. E. Moore is a palm tree widely used in gardening. Due to the continuous production of flowers on the inflorescences, there are fruits and seeds in various stages of maturation on the same plant, making it hard to determine the best fruit maturation stage for obtaining vigorous seeds. This study measured the biometric characteristics of the fruit at different stages of maturation and identified the best fruit maturation stage from which to obtain seeds with optimal physiological quality. Mature fruits were harvested from the tops of 10 trees and the ground, categorized according to their maturation stage and measured for overall length, equatorial diameter, and fresh weight. An experiment to identify the best fruit maturation stage for obtaining seeds of the *V. merrilli* with satisfactory physiological quality was carried out in a greenhouse, with five treatments (maturation stage) and ten replications; each plot was composed of 20 seeds. Plant height, root length, stem diameter, root and above ground dry weight, total dry weight, and Dickson's quality index were measured. The green fruit stage is the most suitable for obtaining seeds of *V. merrilli* with the best physiological qualities. The fruits at the dark red maturity stage had the greatest length, while the those in the green transition stage had the greatest diameter and fresh weight.

Index terms: *Arecaceae*; pearson's correlation; fruit coloration; green transition stage.

RESUMO

*Veitchia merrilli (*Becc) H. E. Moore é uma palmeira muito utilizada na jardinagem. Devido à produção contínua de flores nas inflorescências, há frutos e sementes em vários estágios de maturação em uma mesma planta, dificultando a determinação do melhor estágio de maturação dos frutos para obtenção de sementes vigorosas. Este estudo mesurou as características biométricas do fruto em diferentes estádios de maturação e identificou o melhor estádio de maturação do fruto para obter sementes com ótima qualidade fisiológica. Frutos maduros foram colhidos da copa de 10 árvores e do solo, categorizados de acordo com seu estágio de maturação e caracterizados quanto ao comprimento total, diâmetro equatorial e massa fresca. Um experimento para identificar o melhor estádio de maturação dos frutos para obtenção de sementes de *V. merrilli* com qualidade fisiológica satisfatória foi realizado em casa de vegetação, com cinco tratamentos (estágio de maturação) e dez repetições; cada parcela foi composta por 20 sementes. Altura da planta, comprimento da raiz, diâmetro do caule, peso seco da raiz e da parte aérea, peso seco total e índice de qualidade de Dickson foram medidos. O estádio de fruto verde é o mais indicado para a obtenção de sementes de *V. merrilli* com as melhores qualidades fisiológicas. Os frutos no estádio de maturação vermelho escuro apresentaram o maior comprimento, enquanto os do estádio de transição verde apresentaram o maior diâmetro e massa fresca.

Termos para indexação: *Arecaceae*; correlação pearson; coloração dos frutos; estádio green transition.

INTRODUCTION

Veitchia merrilli (Becc) H. E. Moore (Arecaceae*)* is a species of perennial palm, popularly known as Christmas palm or Manila palm, widely used in landscaping. There is a great demand for this palm to decorate homes, businesses, and public squares (Balqis et al., 2016). Its center of origin is the Philippines, and plants can reach up to 10 meters in height. Propagation is sexual, and ripe fruits are reddish and oval (Luna et al., 2014).

The success of seed germination depends on several factors, including physiological quality, vigor, moisture content, and seed viability (Barroso et al., 2017). To obtain seeds of high physiological quality, it is important to define the ideal harvest time, which often corresponds to the moment when it reaches physiological maturity (Silva et al., 2019). Thus, knowing the physiological maturation process of seeds helps to identify the period when they reach their best physiological quality and the best time to harvest the fruit (Emmanouilidou et al., 2020; Arena et al., 2021; Ramos et al., 2021). Physicochemical characteristics, such as fruit color, size and weight, and total soluble solids content, can indicate the ripening stage of the fruit (Barroso et al., 2017; Arena et al., 2021). The identification of the point of physiological maturity based on the color of the fruit epicarp is essential to determining the best harvest stage (Carvalho; Nakagawa, 2012).

Plant biometry is a useful tool in sustainable plant management. It involves analyzing morphological characteristics of the plant as a whole, or of different parts of the plant, such as fruits and seeds (Silva et al., 2017; Bicalho et al., 2020). The seeds grow quickly in response to the multiplication and development of the cells of the embryonic axis and the reserve tissue. After reaching a maximum, seed size is maintained until the end of the seed maturation cycle, when it undergoes dehydration (Carvalho; Nakagawa, 2012). If the embryonic axis and reserve tissue are well-formed, the seeds show greater vigor, which is important for successful sexual propagation (Rosa et al., 2019). Biometry also assists in the evaluation of genetic variability within and between populations and makes it possible to determine if variability is related to edaphoclimatic factors (Gonçalves et al., 2013; Barroso et al., 2016; Zuffo et al., 2019).

Due to the continuous production of flowers in the inflorescences of palm trees, at any one time, there are fruits and seeds in various stages of maturation on the same plant, making it difficult to determine the best stage of fruit maturation for vigorous harvesting seeds. Thus, the study of seed maturation is important for determining the ideal point of harvest for the production of quality seeds with high dry matter content, germination rate, and vigor (Carvalho; Nakagawa, 2012). There are no studies on the biometry of fruits and seeds of *V. merrilli* at different stages of maturation, and the best time to collect fruits for seedling production is not known. This study aimed to determine the biometric characteristics of fruit at different stages of maturation and to identify the optimal fruit maturation stage to obtain seeds of *V. merrilli* of physiological quality.

MATERIAL AND METHODS

Fruit biometrics

Fruits were harvested from gardens in the city of Nova Xavantina (14’ 40” S; 52° 20’ 45” W) at 271 m a.s.l., in the eastern part of Mato Grosso State, Brazil. The climate of the region is type Aw, in the Köppen classification, with two well-defined seasons: a dry season generally from May to September, and a rainy season from October to April, with an average annual temperature of 24 °C and an average rainfall of 1,500 mm (Silva; Assad; Evangelista, 2008).

Ripe fruits were harvested from the tops of 10 trees and the ground and scored for the stage of ripeness (Table 1) on 11/28/2021. After harvest, the malformed, eaten, and damaged fruits were removed and quickly washed. Within each ripeness stage, the fruits were divided into two; one part being used to measure biometric attributes and the other to determine the effect of the fruit maturation stage on seedling production.

Table 1: Visual characterization of palm *Veitchia merrilli* (Becc) at different maturation stages.

Stage	Coloration of epicarp	Visual characterization
1		Green fruit-green epicarp
2		Green transition-40% green, 40% yellow and 20% red
3		Yellow transition-20% yellow and 80% red
4		Red fruit – red epicarp
5		Dark red fruit-dark red epicarp, picked from the ground

A sample of 120 fruits was taken randomly from different palms in the garden. One hundred visually healthy, whole, and un-deformed fruits were taken for biometric characterization. The following fruit parameters were measured: length (LFL), equatorial diameter (EDF) (using a digital caliper (Clarke-150 mm)), and fresh weight (FM). The data were analyzed by frequency distribution using the program BIOESTAT 5.0 (Ayres; Ayres Júnior; Santos, 2007).

Morphological features of *Veitchia merrilli* (Becc) palm seeds

The water content of the fruit was determined by weighing four replicates of 10 fruits of each maturity stage, drying them in an oven at 105 °C ±1 °C for 24 h, then storing them in a desiccator for later weighing (Brasil, 2009).

The experiment was conducted in a greenhouse from November 2021 to January 2022. The average environmental conditions during the trial, measured daily at midday using a digital thermo-hygrometer (ITHT 2250) were: average air temperature of 30 °C (±5 °C) and relative humidity of 80% (±5%).

The experimental design was completely randomized, with five treatments (maturity stage; Table 1) and ten replicates; each plot contained 20 seeds. The commercial substrate Plantmax HT® was used for growing the seeds. The substrate had the following characteristics: pH in $CaCl_2$ of 5.9; 0.58% C; 680 mg kg^{-1} P; 2.90 $cmol_c$ kg^{-1} K^+; 7.80 $cmol_c$ kg^{-1} Ca^{2+}; 7.50 $cmol_c$ kg^{-1} Mg^{2+}; 18.60 $cmol_c$ kg^{-1} cation exchange capacity (CEC). The substrate was placed in perforated plastic bags with a capacity of 450 mL (12 cm x 8 cm x 6 cm).

At 60 days after sowing, the following measurements were taken: plant height (cm)-determined from the soil surface to the insertion of the last leaf; root length (cm)-called pivotal root; stem diameter (cm)-measured at the height of the neck of the plant on the soil surface using a digital pachymeter (Clarke-150 mm), with a precision of ±0.01 mm. The seedlings were then separated into the aerial part and root system, placed in paper bags, and placed in a forced circulation oven for 72 h at 65 °C (±1.0 °C) to determine their dry mass and weighed on an analytical balance to a precision of 0.001 g. From these measurements, the total dry matter (TDM) was determined, and the Dickson quality index (DQI) was calculated (Equation 1; Dickson et al., 1960):

$$DQI = \frac{TDM}{\left(\frac{PH}{SD}\right)+\left(\frac{SM}{RM}\right)} \quad (1)$$

where TDM = total dry matter (g); PH = plant height (cm); SD = stem diameter (mm); SM = shoot dry matter (g); and RM = root dry matter (g).

Data analysis

The data were tested for homoscedasticity of variances (Levene test; $p > 0.05$) and normality of residuals (Shapiro-Wilk test; $p>0.05$). The fruit biometric data were analyzed using descriptive statistics with univariate analysis, using measures of central tendency and variability or dispersion. Statistical correlations based on Pearson's correlation networks (threshold set at 0.6, $p<0.05$) were performed between the different morphophysiological characteristics of *V. merrilli* seedlings. The correlation network was used to graphically illustrate Pearson's correlation analyses, in which the proximity between the nodes is proportional to the absolute correlation values between the morphophysiological traits. The relative thickness and color density of the bands indicate the strength of Pearson correlation coefficients, and the color of each band indicates a positive or negative correlation (red for negative and green for positive). Canonical correlation analysis (CCA) was used to study the interrelationship between sets (vectors) of independent (fruit maturation stage) and dependent (morphological traits) variables. These analyses were performed using Rbio software version 140 for Windows (Rbio Software, UFV, Viçosa, MG, BRA).

RESULTS AND DISCUSSION

Fruit biometry

Fruit length reached its maximum mean value (32.27 mm) at the dark red stage and minimum (29.03 mm) at the yellow transition (Table 2). The lowest average fresh fruit weight (4.78 g) was also recorded at the dark red fruit stage and maximum at the green transition. The equatorial diameter of the fruit had a minimum mean value (17.71 mm) at the dark red fruit stage and a maximum (20.11 mm) at the green transition (Table 2). The coefficient of variation (CV) for fruit length and the equatorial diameter of the fruit at all stages were below 10%, indicating low variability. For the fresh fruit weight, with the exception of the green transition stage (CV 8.58%), all maturity stages had values between 10.63% and 17.08%, indicating an intermediate level of variability.

The data frequency distribution for each fruit parameter was different at each maturity stage, with the exception of the LFL for green fruit and green transition stages, which were the same (Figure 1). In the green fruit and green transition stages, the LFL values ranged from 26.21 to 33.82 mm, with about 60% and 40% of the fruit ranging from 28.74 to 30.01 mm and 30.01 to 31.28 mm, respectively (Figure 1a and Figure 1d). EDF ranged from 16.16 to 21.50 mm over all maturity stages. In the green fruit maturity stage, about 30% of EDF values ranged from 18.83 to 19.72 mm (Figure1b). FM values ranged from 3.41 to 7.73 g over all maturity stages. In the green fruit

maturity stage, about 40% of fruit weight ranged from 5.57 to 6.29 g (Figure 1c). In the green transition stage, 60% of EDF values were between 19.72 and 20.61 mm (Figure1e), and 40% of FM values fell within each of two size classes ranging from 5.57 to 6.29 g and 6.29 to 7.01 g (Figure 1f).

In the yellow transition stage, 60% of the fruit had LFL values from 28.74 to 30.01 mm (Fig. 1 g); the EDF had 40% of the fruit within two size classes between 18.83 to 19.72 mm and 19.72 to 20.61 mm (Figure 1 h); and 40% of FM values were between 5.57 and 6.29 g (Figure 1i). In the red fruit maturity stage, 60% of fruits had LFL values between 28.74 to 30.01 mm (Figure 1j); 40% of fruits had EDF values ranging from 18.83 to 19.72 mm (Figure 1 l); and 40% of fruit had FM values ranging from 5.57 to 6.29 g (Figure 1 m). In the dark red fruit maturity stage, 40% of fruit had LFL values between 31.28 to 32.55 mm (Figure 1n); 40% of fruit had EDF values ranging from 17.94 to 18.83 mm (Fig. 1o); and 30% of fruit had FM values ranging from 4.13 to 4.85 g and 5.57 to 6.29 g (Figure1p).

Fruits in the dark red maturity stage had a higher LFL value than other maturity stages (Figure 1n), while the highest EDF and FM were in the green transition stage (Figure 1e and 1f, respectively). Thus, EDF and FM are linked to the water content of the fruit and seed. The size of the seed, once it reaches a maximum, is maintained for a period, after which it undergoes intense dehydration and reduces in size (Carvalho; Nakagawa, 2012).

The first stages of embryogenesis are marked by intense cell division and expansion, leading to a progressive increase in seed size, and reaching a maximum approximately in the middle of the dry matter accumulation period (Marcos Filho, 2005). Several factors influence the development of a plant, and these may vary between species and even within species. Fruits are strong sinks, and the larger they become on the mother plant, the greater their vigor and that of their seeds, reflecting the plant's ability to produce chemical constituents (Rosa et al., 2019).

Table 2: *Veitchia merrilli* palm fruit biometric data. N = 100 fruits.

Parameters	Average[1]	Asymmetry	Kurtosis	S.D.[2]	C.V.(%)[3]
Green fruit					
Length of fruit (mm)	30.03(0.21)	-0.26	0.25	1.02	2.23
Equatorial diameter of fruit (mm)	19.13(0.26)	-0.45	0.25	1.04	4.42
Fresh mass of fruit (g)	5.66(0.19)	-0.60	0.55	1.11	10.63
Green transition					
Length of fruit (mm)	29.82(0.15)	0.01	-2.23	1.01	1.66
Equatorial diameter of fruit (mm)	20.11(0.25)	-0.57	2.32	1.04	3.96
Fresh mass of fruit (g)	6.57(0.17)	0.65	1.05	1.08	8.56
Yellow transition					
Length of fruit (mm)	29.03(0.40)	-1.44	1.64	1.04	4.38
Equatorial diameter of fruit (mm)	18.74(0.45)	-0.60	-1.02	1.08	7.66
Fresh mass of fruit (g)	5.73(0.28)	-0.48	-0.87	1.17	15.64
Red fruit					
Length of fruit (mm)	29.44(0.26)	-0.98	0.31	1.02	2.82
Equatorial diameter of fruit (mm)	19.44(0.28)	0.24	-1.10	1.04	4.67
Fresh mass of fruit (g)	6.32(0.22)	0,03	-1.43	1.19	11.23
Dark red fruit					
Length of fruit (mm)	32.27(0.33)	-0.02	-1.10	1.03	3.30
Equatorial diameter of fruit (mm)	17.71(0.28)	-0.21	-0.85	1.05	5.15
Fresh mass of fruit (g)	4.78(0.25)	0.05	0.43	1.19	17.08

[1]In parentheses standard error of the mean; [2]S.D.: Standard Deviation; [3]C.V.: coefficient of variation.

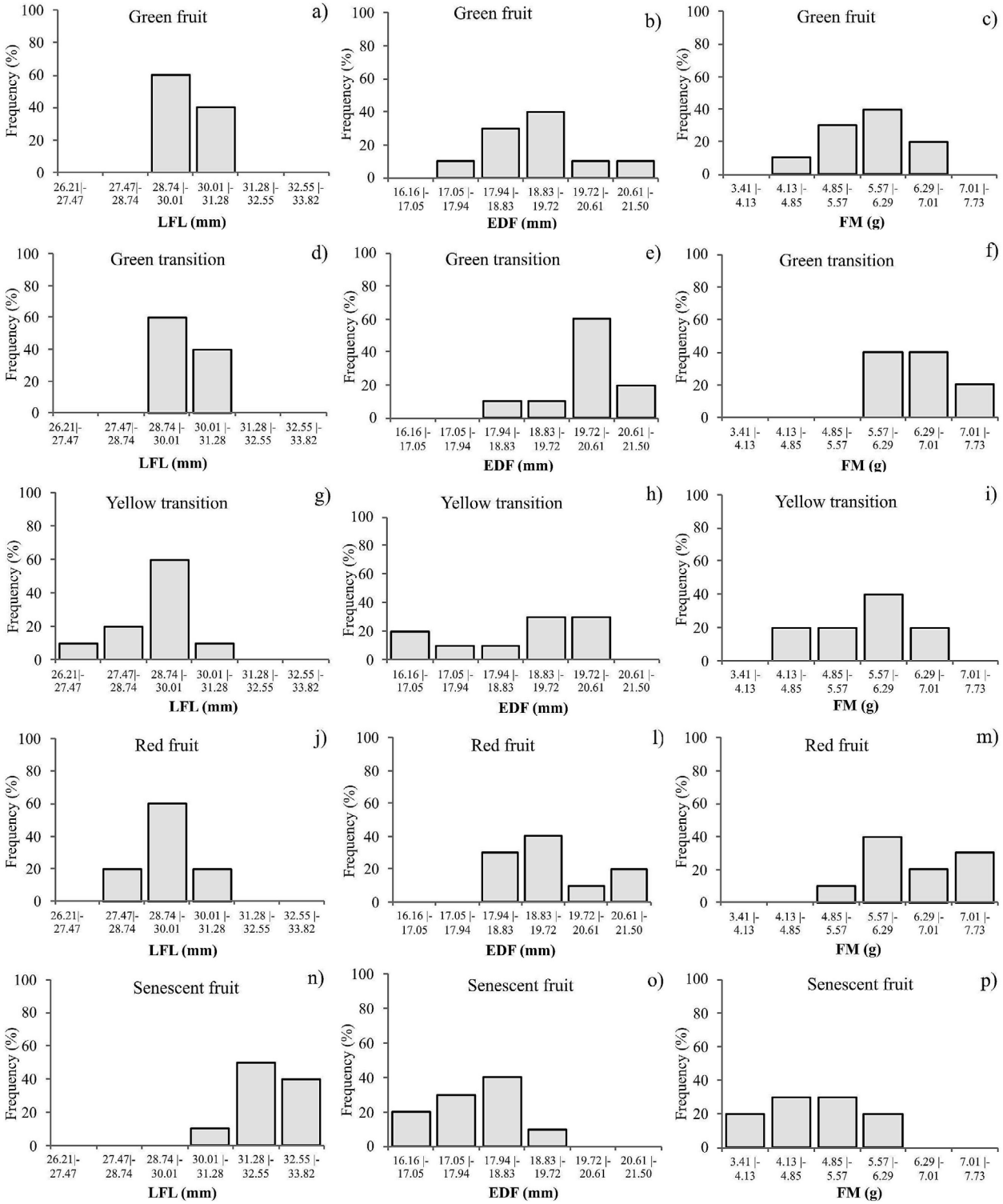

Figure 1: Fruit length (LFL), equatorial fruit diameter (EDF), and fresh weight (FM) of the fruit of *Veitchia merrilli* at five maturity stages: green fruit (a-c), green transition (d-f), yellow transition (g-i), red fruit (j-m), dark red fruit (n-p), in Nova Xavantina, MT. N = 100 fruit.

Morphological characteristics and quality of seedlings

The water content in the seeds and fruits reduces during the fruit maturation process (Table 3). The reduction of water content in seeds allows their viability to be maintained for longer because their metabolism is reduced due to the decrease in respiratory activity, inducing a state of dormancy; a state that is also influenced by the phytohormone abscisic acid (Faria et al., 2016; Bareke, 2018). Although drying is necessary for the development of metabolic processes associated with germination (Bewley et al., 2013), the water content of seeds cannot be considered the best indicator of physiological maturity because it can be affected by environmental conditions and genotype (Vidigal et al., 2011).

V. merrilli seedlings had greater height, stem diameter, shoot and root dry mass, and consequently, greater Dickson quality index when germinated from fruit at the green transition stage, when water content of the seed plus the fruit was 68% (Table 3). As mentioned earlier, fruits are strong sinks, and the larger they are on the mother plant, the greater the seed vigor tends to be (Rosa et al., 2019). Fruits at the green transition stage had the greatest equatorial diameter and fresh weight. Maximum dry weight is reached when seeds have a relatively high water content (Marcos Filho, 2005), and it has been identified as the best index of seed maturation. In addition, the maximum dry weight is what determines the point of physiological maturity (Carvalho; Nakagawa, 2012). The greatest root length was obtained from seedlings produced from fruits collected at the red fruit stage.

Seeds harvested from fruit already in the dark red stage are sometimes considered to be of better physiological quality; however, this was not observed in the present study. A maturity index based only on the skin and flesh color may be limited in identifying the optimal maturity stage, and it is necessary to observe other attributes as well (Emmanouilidou et al., 2020).

Canonical correlation analysis was used to verify the contribution of each dependent variable measured in the palm seedlings as affected by the fruit maturation stages (Figure 2). For scores to be represented in a two-dimensional graph, the percentage of retained variance must be higher than 80% (Mingoti, 2005). In this study, variances accumulated in the two main canonical variables were 98.6% (Figure 2), allowing an accurate interpretation. An angle between vectors of less than 90° indicates a positive correlation between the dependent variables: plant height, stem diameter, shoot dry matter, root dry matter, and Dickson Quality Index with the fruits harvested in stage 2 (green transition) and root length (RL) with the fruits harvested at stage 4 (red fruit).

Fruits harvested at maturity stage 2 (green transition-40% green, 40% yellow, and 20% red) produced seedlings with better qualities based on plant height, stem diameter, shoot dry matter, root dry matter, and Dickson Quality Index (Figure 2). Green transition fruits also had higher values of the equatorial diameter of fruit and fresh weight (Figure 1e and 1f, respectively). Seed size can be used as a parameter to obtain more uniform germination and seedlings of a standardized size and vigor Carvalho and Nakagawa (2012), and physiological maturity is defined as the point at which the seed shows maximum vigor and germination. For *V. merrilli*, the green transition maturity stage was the point at which seedling quality was highest, demonstrating that the seed reached physiological maturity at this time.

Seed germination and seedling vigor are related to the fruit development stage. Thus, it is evident that in maturity stage 2 (green transition), the reserves contained in the mesocarp associated with the nutrients present in the substrate were sufficient to produce *V. merrilli* seedlings with the best Dickson quality index (Figure 2).

Table 3: Mean ±standard deviation of morphological characteristics and Dickson quality index in *Veitchia merrilli* seedlings originating from fruits at different stages of maturation.

Maturation stage		WC (%)	PH (cm)	RL (cm)	SD (mm)	SM (g)	RM (g)	DQI
1	Green fruit	70	14.17 ±2.36	14.83 ±4.19	4.52 ±0.16	0.41 ±0.18	0.16 ±0.07	0.10 ±0.04
2	Green transition	68	18.33 ±1.53	15.33 ±1.53	5.96 ±0.49	0.84 ±0.14	0.38 ±0.04	0.23 ±0.01
3	Yellow transition	68	16.83 ±1.04	15.33 ±3.21	4.75 ±0.56	0.60 ±0.11	0.25 ±0.10	0.14 ±0.05
4	Red fruit	65	15.00 ±1.00	20.00 ±3.61	5.00 ±0.07	0.59 ±0.09	0.32 ±0.09	0.19 ±0.04
5	Dark red fruit	50	14.00 ±1.00	12.67 ±3.51	4.72 ±0.29	0.46 ±0.19	0.22 ±0.09	0.13 ±0.05

Abbreviations: WC: water content of the seed plus the fruit, PH: plant height, RL: root length, SD: stem diameter, SM: Shoot dry matter, RM: root dry matter, DQI: Dickson Quality Index.

There was a strong correlation of DQI with root and shoot dry weight (Figure 3), and dry weight of roots and shoot are strongly correlated with plant height. Root length is weakly correlated with all variables (Figure 3). Dickson's quality index (DQI) is considered an excellent indicator of seedling quality because it incorporates several variables (Dickson; Leaf; Hosner, 1960). Thus, by choosing seedlings with high root and shoot dry matter, the nurseryman is also choosing seedlings of *V. merrilli* with a high Dickson's quality index.

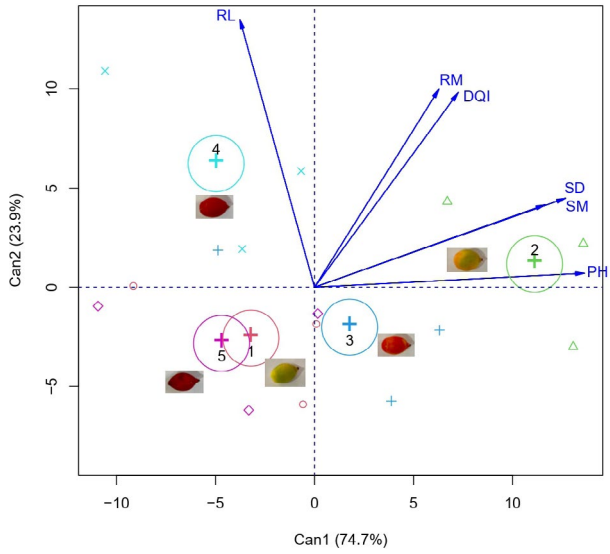

Figure 2: Canonical correlation analysis (CCA) between the variables and their canonical variates in *Veitchia merrilli*. The blue lines show the canonical correlation between centroids of the first pair of canonical variates and the lineal tendency line. Abbreviations: PH: plant height, SD: stem diameter, RL: root length, SM: Shoot dry matter, RM: root dry matter, DQI: Dickson Quality Index.

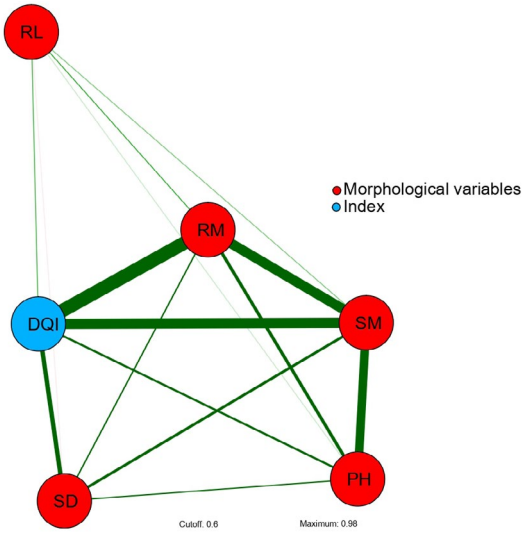

Figure 3: Correlation networks showing the most significant Pearson's correlations between the morphological and physiological traits of *Veitchia merrilli*. Thicker and green lines represent the highest positive correlations (threshold set at 0.6 and p-values <0.05). Thicker and red lines represent the highest negative correlations (threshold set at 0.6 and p-values <0.05). Abbreviations: PH: plant height, SD: stem diameter, RL: root length, SM: Shoot dry weight, RM: root dry weight, DQI: Dickson Quality Index.

CONCLUSIONS

The green fruit maturity stage is best for obtaining seeds of *Veitchia merrilli* palm of satisfactory physiological quality. The fruits of the dark red fruit stage had the greatest length, while fruits in the green transition stage had the greatest diameter and fresh weight.

AUTHOR CONTRIBUTION

Conceptual idea: Zuffo, A.M., Methodology design: Zuffo, A.M., Ratke, R.F., Data collection: Zuffo, A.M., Ratke, R.F., Aguilera, J.G., Data analysis and interpretation: Zuffo, A.M., Ratke, R.F., Aguilera, J.G., Barrozo, L.M., Fonseca, W.L. and Writing and editing: Zuffo, A.M., Ratke, R.F., Aguilera, J.G., Barrozo, L.M., Fonseca, W.L.

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