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RESEARCH ARTICLE

Physiological and biochemical responses of oil palm (*Elaeis guineensis* Jacq.) in relation to fresh fruit bunch yield under the influence of different methods and levels of irrigation at different crop factors

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ABSTRACT

The present investigation was carried out on eighteen years old oil palm plantation at ICAR-Indian Institute of Oil Palm Research, Pedavegi, Andhra Pradesh with different methods and levels of irrigation water using crop factors to find out their influence on the physiological and biochemical responses in relation to yield of fresh fruit bunches. The result obtained has significantly indicated the highest relative water content (97.44%) and membrane stability index (25.26%) were observed with drip method of irrigation. Among the levels of irrigation, the highest relative water content (95.51%), membrane stability index (27.11%) were found signficantly highest with crop factor 0.8. Among the interaction effects, the relative water content (98.00%), membrane stability index (28.85%) were found signficantly highest with drip method of irrigation using crop factor 0.8. Significantly the highest proline content (2.37%) was recorded highest with drip method of irrigation. Among the levels of irrigation, proline (2.56%), lipid peroxidation (8.73n moles g^{-1}) activities was found signficantly highest with crop factor 0.8. Among the interaction effects, signficantly highest proline (2.77%), and lipid peroxidation (9.03n moles g^{-1}) activity were observed with drip method of irrigation using crop factor 0.6. The data pertaining to yield attributes has revealed that significantly the yield of fresh fruit bunches (19.84t/ha) were observed with micro-jet method of irrigation. Among the levels of irrigation, the number of fresh fruit bunches per palm per year (7.03), yield of fresh fruit bunches (19.83t/ha) were found significantly highest with crop factor 0.8.

Key words: Membrane stability index, oil palm, relative water content, proline, lipid peroxidation and fresh fruit bunch.

INTRODUCTION

Oil palm (*Elaeis guineensis* Jacq.) is an introduced crop into India for its valuable edible and industrial oil. The crop is strictly tropical in nature for its growth and development. The performance of oil palm is considered satisfactory in areas endowed with hot and humid tropical climate with optimal temperatures ranging between 80-90° F and average annual rainfall ranging between 2000- 3000 mm with well distribution for a larger part of the year. Zhu et al. (2008) reported that plants receiving direct sunlight for minimum of 5-7 hours per day have been found very much beneficial for optimal growth and development. So, availability of adequate moisture coupled with optimum temperature has been identified as the important factors in determining the yield of oil palm. Irrigation trials conducted on the performance of oil palm have shown positive response to irrigation in terms of growth and yield. Water availability in the soils of oil palm plantation plays an important role for its proper growth (Henson and Harun 2005) and functions as a signal for female sex representation (Jone 1997). In areas of water shortage, it is observed that a large number of male flowers are produced which is coupled with slow growth leading to poor yields Prasad et al. 2000). The basic information relating to water stress responses in oil palm is a prime topic of the day which should be investigated further for screening of tolerant lines for water deficit coupled with their physiological efficiency (Murugesan and Rethinam 2000). Water deficit is a major abiotic stress, which is widely distributed worldwide over 1.2 billion hectares, especially in the rain-fed areas (Chaves and Oliveira 2004; Kijne 2006; Passioura, 2007). Application of irrigation water as supplemental dose has been reported by several workers to increase the yield of fresh fruit bunches (Gawankar et al. 2003; Rao, 2009; Gajbhiye et al. 2011; Sanjeevraddi et al. 2014). Keeping all these things in view the present investigation has been planned to investigate the influence of methods of irrigation water in conjunction with evapotranspiration based level of irrigation using crop factors with the intension of maximizing the yield of fresh fruit bunches and understanding the physiological responses of photosynthetic pigments in increasing the yield of fresh fruit bunches.

MATERIAL AND METHODS

The present investigation was carried out on the existing eighteen years old oil palm plantation at ICAR-Indian Institute of Oil Palm Research, Pedavegi, Andhra Pradesh and was laid out in a split-plot design with four replications consisting of main plot treatments with two different methods of irrigation systems and three sub-plot treatments of irrigation levels using crop factors based on the rate of evapotranspiration. The level of irrigation water using crop factor was calculated as described below by Rao et al. (2016).

Water requirement of a crop is the quantity of water required by the crop in a given period of time for its optimum growth under field conditions. It is a function of rainfall, soil water reserves and evapotranspiration. Water requirement varies from place to place depending on climatic conditions like sunshine hours, temperature, relative humidity, wind velocity, etc. This is the best available method to estimate crop water requirement from direct measurement of evapo-transpiration. In this method, pan evaporation or penman's estimate of evaporation is multiplied by an appropriate crop factor. Water use of crop is very closely related to evaporation. In fact, crop water use is composed of evaporation of water from the soil surface and transpiration of water through the leaves, combined together these two factors are named as evapo-transpiration. While evaporation is easily measured, transpiration is not. Therefore, it is much simpler to relate the crop evapo transpiration to daily evaporation via a crop factor. A crop factor is related to the per cent of ground covered by the crop canopy and therefore will vary depending on the crop stage. For an adult oil palm, 0.7 is considered as crop factor. The following simple method of calculation has been devised based on the evaporation rates prevailing in the area especially during summer months.

Evaporation from pan evapori meter: 6.70 mm (for example)
Crop factor: 0.7
Potential evapo-transpiration (PE) = Pan evaporation × Crop factor
PE = 6.07 × 0.7 = 4.69 mm/day
46,900 L/day/ha as 1 mm of rainfall is equal to 1 L m^{-2}

Since 143 palms are accommodated in one hectare area, the quantity of water per palm per day works out to be 328 litres.

Water holding capacity at not less than 70% of the field capacity is acceptable and will not affect the FFB yield of oil palm significantly.

Therefore the minimum quantity of water to be applied will be:

4.69 mm × 70% = 3.283 mm/day or 32,830 L/ha/day or 220 L/palm/day.

The two methods of irrigation systems adopted were micro-jet and drip, while the three irrigation levels used were based on Crop Factors (CF) 0.6, 0.7 and 0.8. The treatments were: T_1: Micro-jet method of irrigation system using irrigation level crop factor 0.6; T_2: Micro-jet method of irrigation system using irrigation level crop factor 0.7; T_3: Micro-jet method of irrigation system using irrigation level crop factor 0.8; T_4: Drip method of irrigation system using irrigation level crop factor 0.6; T_5: Drip method of irrigation system using irrigation level crop factor 0.7; T_6: Drip method of irrigation system using irrigation level crop factor 0.8. Measurement of water content in a tissue is expressed either on fresh weight or dry weight basis, has been recently replaced by the measurement based on maximum amount of water a tissue can hold. These measurements were referred to as relative water content. The method used was as per the procedure outlined by Catsky (1974). Membrane Stability Index of plant tissue was measured as per the procedure explained by Sairam *et al.* (2002). Proline content of fresh leaves of each treatment was determined by using rapid colorimetric method as suggested by Bates *et al.* (1973). The proline concentration in the sample was determined based on the standard curve using analytical grade proline (SRL, Mumbai) and calculated on fresh weight basis. The level of lipid peroxidation in the leaf tissue was measured in terms of malondialdehyde (MDA, a product of lipid peroxidation) content determined by the thiobarbituric acid (TBA) reaction with minor modification of the method of Heath and Packer (1968).Number of Fresh fruit Bunches per palm were recorded in every harvest and expressed on yearly basis as number of fresh fruit bunches per palm per year. Average yield of fresh fruit bunches per palm in each treatment was multiplied with number of palms planted per hectare (143 palms) and expressed in tonnes. The data thus arrived was subjected to statistical analysis as per the procedure outlined by Panse and Sukhatme (1985).

RESULTS AND DISCUSSION

Significant differences were observed in the relative water content (Table 1) of leaves with different methods and levels of irrigation. Significantly highest relative water content (97.44 %) in the leaves was observed with drip method of irrigation than micro-jet method of (91.71 %) of irrigation. Among the irrigation levels, significantly highest relative water content (95.51 %) was observed by application of irrigation water using crop factor 0.8. Interaction effect of RWC between methods and levels of irrigation water using crop factor was found non-significant. However, highest relative water content (98.00 %) of leaves was observed with drip method of irrigation using crop factor 0.8, whereas, lowest (90.82 %) RWC was observed with micro-jet method of irrigation using crop factor 0.7. Relative water content in the leaves of oil palm irrigated with micro-jet or drip method of irrigation has shown no definite trend with the amount of irrigation level increased. Maintenance of normal physiological processes under stress conditions require sufficient cell turgidity or relative water content with less injury to the cell membrane. A small quantity of water loss should therefore cause a shift in turgor so that the leaves tend to maintain high relative water content to retain a high symplast volume which indicates that under water deficit conditions the maintenance of high relative water content is more important in conferring the drought tolerance in the palms. Sun et al. (2011) reported that relative water content in the leaves is integrated with physiological traits regulated by water stress.

Significant differences were observed in the membrane stability index (Table 1) of oil palm leaves with different methods and levels of irrigation. Significantly highest membrane stability index (25.26%) of the leaves was observed with drip method of irrigation than micro-jet method of (19.75%) of irrigation. Among the levels of irrigation, significantly the highest membrane stability index (27.11%) was

Table 1 Effect of methods and levels of irrigation using crop factors on physiological and biochemical responses to yield of oil palm

Treatments	Relative water content (%)	Membrane stability index (%)	Proline (%)	LOX activity (n moles g^{-1} FW)	Number of fresh fruit bunches per palm	Yield of fresh fruit bunches (t/ha)
Irrigation methods (M)						
M_1 (Micro-jet)	91.71	19.75	2.01	7.20	6.43	19.84
M_2 (Drip)	97.44	25.26	2.37	7.45	6.45	18.17
LSD (p = 0.05)	0.917	1.222	NS	NS	NS	NS
Irrigation levels (L)						
(L_1) Crop factor 0.6	94.54	17.25	2.56	8.73	5.49	17.57
(L_2) Crop factor 0.7	93.67	23.15	1.93	6.51	7.03	19.83
(L_3) Crop factor 0.8	95.51	27.11	2.07	6.74	6.80	19.61
LSD (p = 0.05)	0.956	1.796	0.514	1.262	1.010	1.944
Interaction of M x L						
M_1L_1	91.29	13.01	2.36	8.43	5.77	18.62
M_1L_2	90.82	20.87	1.73	5.81	7.09	19.55
M_1L_3	93.01	25.38	1.94	7.36	6.43	19.68
M_2L_1	97.78	21.48	2.77	9.03	5.22	16.51
M_2L_2	96.52	25.44	2.12	7.21	6.97	18.44
M_2L_3	98.00	28.85	2.21	6.11	7.16	21.23
LSD (p = 0.05)	NS	2.709	NS	NS	NS	NS

observed by application of irrigation water using crop factor 0.8, whereas, significantly the lowest membrane stability index (17.25%) was observed by application of irrigation water using crop factor 0.6. Interaction effect between methods of irrigation and levels of irrigation water using crop factors on membrane stability index was found significant. Significantly the highest membrane stability index (28.85%) was observed by application of irrigation water using crop factor 0.8 through drip method of irrigation, whereas, significantly the lowest membrane stability index (13.01%) was recorded by application of irrigation water using crop factor 0.6 through micro-jet method of irrigation. Abbas, 2012 reported that drought, salinity, high and low temperatures damages the structure of cell membrane thereby leading to an increase in the membrane permeability and thus resulting in the leakage of intracellular contents. Maintenance of membrane structure and integrity is the key factor in the water stress tolerance. Membrane integrity is usually determined by reducing the leakage of solutes (electrolytes, sugars, amino acids, organic acids and hormones) from cells. The capacity of stem for mobilization or translocation of reserves appears to be related to drought tolerance or resistance which could be due to accumulation of ABA in response to water stress.

The data were found significant with different levels of irrigation. Among the levels of irrigation, significantly the highest proline content (2.56 %) was observed with the application of water using crop factor 0.6, whereas, significantly the lowest proline content (1.93 %) was observed with the application of water using crop factor 0.7 and was found at par with the application of water using crop factor 0.8 (2.07 %). A decreasing trend in the proline content of oil palm leaves was noticed with an increase in the quantity of application of water. The interaction effect between the methods and levels of irrigation was found non-significant. The highest proline content (2.77 %) in the leaves was observed with the application of water using crop factor 0.6 through drip method of irrigation.
Accumulation of proline content in oil palm leaves has been demonstrated as one of the most evident biochemical indices under severe water stress conditions (Cha-um et al. 2010). Accumulation of large quantities of proline in the leaves contributes to the osmotic adjustment and serves as a cytoplasmic osmotic balance for potassium accumulation as the main osmoticum in the vacuole.

Harun (1997) noticed accumulation of proline content in the leaves of oil palm seedlings under water stress conditions and also observed an increase in the stomatal resistance and a reduction in the leaf water potential due to increased water deficit in the leaves of oil palm. Heuer (1999) reported that accumulation of proline content was due to water stress resulted from a stimulated synthesis which inhibited the degradation or an impaired incorporation of proline into proteins.
Nevertheless, it has been demonstrated that proline plays a more complex role in conferring the drought tolerance in the plants than enacting as a simple osmolyte (Szabados and Savoure 2009). It may protect protein structure by maintaining the structural stability (Rajendrakumar et al. 1994), act as a free radical scavenger (Reddy et al. 2004) as well as involved in the recycling of $NADPH^+$ via glutamate synthesis (Hare and Cress 1997). Proline synthesis may provide some protection against photoinhibition under adverse conditions by restoring the pool of the terminal electron acceptor of the photosynthetic electron transport chain (Szabados and Savoure 2009).

The lipoxigenase activity was found significant with different levels of irrigation. The highest LOX activity (7.45 n moles g^{-1} FW) was recorded in the leaves of oil palm by the application of irrigation water through drip method of irrigation in comparison to micro-jet method of irrigation (7.20 n moles g^{-1} FW).

Among the irrigation levels, application of water by using crop factor 0.6 has recorded significantly the highest LOX activity (8.73 n moles g^{-1} FW), whereas, application of water by using crop factor 0.7 and 0.8 have recorded significantly lower activity of LOX (6.51 n moles g^{-1} FW and 6.74 n moles g^{-1} FW respectively) without any significant differences between the water levels.

The interaction effect between the methods and levels of irrigation was found non-significant. The highest LOX activity (9.03 n moles g^{-1} FW) was recorded by the application of water using crop factor 0.6 through drip method of irrigation. The lowest LOX activity (5.81 n moles g^{-1} FW) was observed by the application of water using crop factor 0.7 through micro-jet method of irrigation.

At cellular level, the impact of water stress is observed based on the integrity of cell membrane and the extent of solute leakage, which is regulated by the cell membrane stability. Normal cell functions are affected due to changes in the peroxidation of cell wall lipids during water stress resulting increased cell membrane permeability and solute leakage (Rajagopal et al. 2005).

The data were found non-significant with regard to the number of fresh fruit bunches per palm by irrigating with different methods of irrigation. The highest number of fresh fruit bunches per palm per year (6.45) was observed with micro-jet method of irrigation than drip method (6.43) of irrigation.

Significant differences were observed among the levels of irrigation using crop factor. Among the irrigation levels, significantly the highest number of fresh fruit bunches per palm per year (7.03) was observed by the application of irrigation water using crop factor 0.7, whereas, significantly the lowest number of fresh fruit bunches per palm per year (5.49) was recorded by application of water using crop factor 0.6.

The interaction effect between the methods and levels of irrigation with regard to number of fresh fruit bunches per palm per year was observed non-significant. The highest number of fresh fruit bunches per palm per year (7.09) was observed with micro-jet method of irrigation using crop factor 0.7, whereas, lowest number of fresh fruit bunches per palm per year (5.22) was observed with drip method of irrigation using crop factor 0.6.

Occurrence of male and female inflorescences in oil palm was observed due to the process of differentiation of vegetative primordia to floral primordia that is known to occur between 27 to 35 months before anthesis and was concurrent with the process of leaf production (Hartley, 1988). Among the reproductive attributes production of female inflorescences appeared to be highly sensitive to water stress showing the reduction. The number of fresh fruit bunches per palm per year depends upon the number of productive female inflorescences.

In the present investigation, it was observed that quantity of irrigation water applied is the same through different methods of irrigation. Hence, it may be concluded that the method of irrigation has no significant impact on the vegetative growth of the plant as well as on the development of reproductive parts mainly the production of female inflorescences thereby influencing production of fresh fruit bunches per palm per year. However, application of irrigation water based on the crop factor at 0.7 was found very influensive in increasing the number of productive female inflorescences there by the number of fresh fruit bunches per palm per year. Gawankar *et al.* (2003), Krishna rao (2009), Gajbhiye *et al.* (2011) and Sanjeevreddi *et al.* (2014) reported similar kind of observations in their earlier reports on oil palm crop and were found in accordance with the present results.

The data pertaining to yield of fresh fruit bunches per palm per year (Table 1) has recorded non-significant differences between the methods of irrigation. However, application of different levels of irrigation water based on crop factors recorded significant differences with regard to yield of fresh fruit bunches per palm per year. Among the levels of irrigation, significantly the highest annual yield of fresh fruit bunches (19.83 t/ha) was observed by application of irrigation water using crop factor 0.7 and was found at par with the application of irrigation water using crop factor 0.8. Significantly the lowest annual yield of fresh fruit bunches per palm per year was observed by application of irrigation water using crop factor 0.6 (17.57 t/ha). Interaction effect between methods of irrigation and levels of irrigation using crop factors on the annual yield of fresh fruit bunches was found non-significant. However, the highest annual yield of fresh fruit bunches (21.23 t/ha) was recorded by drip method of irrigation using crop factor 0.8 followed by micro-jet method of irrigation using crop factor 0.8 (19.68 t/ha). The lowest annual yield of fresh fruit bunches (16.51 t/ha) was observed with drip method of irrigation using crop factor 0.6. the number of fresh fruit bunch production in oil palm depends upon the number of productive female inflorescences produced. A small reduction in the number of leaves produced due to shortage of water showed an amplification of inhibitory effect on the number of female inflorescences produced thereby a reduction was observed in the number of fresh fruit bunches per palm per year which ultimately led to a reduction in the annual yield of fresh fruit bunches. A small shortage in the application of irrigation water to the palms showed a reduction in the number of female inflorescences produced accordingly the number of fresh fruit bunches produced was influenced which led to a reduction in the annual yield of fresh fruit bunches per palm per year. Gawankar et al. (2003) and Rao (2009) also reported similar kind of observations on oil palm which supports the present investigation.

Based on the results obtained, it could be observed that several of the physiological and biochemical parameters were influenced by supplemental irrigation water applied at different levels based on the crop factors rather than the method of irrigation during the critical periods of growth and development, which ultimately influenced the final output in terms of FFB yield. An increase in the level of irrigation water led to better maintenance of relative water content and membrane stability index in the plant, which favored opening of stomata thus taking gaseous exchange which ultimately favored accumulation of more photo-assimilates which contributed for better growth and development in terms of fresh fruit bunches.

REFERENCES

Abbas SM. (2012). Effects of low temperature and selenium application on growth and the physiological changes in sorghum seedlings. *J Str.Physio. and Biochem* (8): 268-286.

Bates LS, Waldeen RP, Teare ID. (1973). Rapid determination of free proline for water stress studies. *Plant and Soil*. (39): 205-07.

Catsky J. (1974). Water saturation deficit (Relative water content). In: SLAVIK, B. (Ed.) methods of studying plant water relations. *Berlin, Springer-Verlag* 136-156.

Cha-um S, Takabe T. Kirdmanee C. (2010). Osmotic potential, photosynthetic abilities and growth characters of oil palm (*Elaeis guineensis* Jacq.) seedlings in responses to poly ethylene glycol induced water deficit. *African Journal of Biotechnology* 9(39): 6509-16.

Chaves MM, Oliveira MM. (2004). Mechanisms underlying plant resilience to water deficits: prospects for water saving agriculture. *Journal of Experimental Botany* 55: 2365-84.

Gajbhiye RC, Gawankar MS, Arulraj, S Patil SL. (2011). Evaluation of drought tolerant oil palm genotypes for their performance in Konkan Region of Maharashtra. *Journal of Plantation Crops* 39(1): 161-63.

Gawankar MS, Devmore JP, Jamadagni BM, Sagvekar VV, Hameedkhan H. (2003). Effect of water stress on growth and yield of tenera oil palm. *J Applied Hort* **5**(1): 39-40.

Gawankar MS, Devmore JP, Jamadagni BM, Sagvekar VV Hameedkhan H. (2003). Effect of water stress on growth and yield of tenera oil palm. *Journal of Applied Horticulture* 5(1):39-40.

Hare PD, Cress WA. (1997). Metabolic implications of stress induced proline accumulation in plants. *Plant Growth Regulation* 21: 79–102.

Hartley CWS. (1988). *The Oil Palm*, Third Edition. Harlow, England, Longman. Harun MH. (1997). Proline accumulation in the leaves of water stressed oil palm (*Elaeis guineensis* Jacq.) seedlings. *Elaeis* 9: 93-99.

Heath RL, Packer L. (1968). Photoperoxidation in isolated chloroplasts. I. Kinetics and stoichiometry of fatty acid peroxidation. *Archives of Biochemistry and Biophysics* 125: 189-98.

Henson IE, Harun MH. (2005). The influence of climatic conditions on gas and energy exchanges above a young oil palm stand in north Kedah, Malaysia. *Journal of Oil Palm Research* 17: 73-91.

Heuer B. (1999). Osmoregulatory role of proline in plants exposed to environmental stresses. *In*: Pessarakli, M. (*Ed.*), *Handbook of Plant and Crop Stress. Marcel Dekker,* New York 675-95.

Jone LH. (1997). The effect of leaf pruning and other stresses on sex determination in the oil palm and their representation by a computer simulation. *Journal of Theoretical Biology* 187: 241-60.

Kijne JW. (2006). Abiotic stress and water scarcity: Identifying and resolving conflicts from plant level to global level. *Field Crops Research* 97: 3-18.

Krishnarao K. (2009). Effect of different methods of irrigation and nutrient requirement on yield of oil palm. *International Journal of Oil Palm Research* 6(1):31-34.

Panse VG, Sukhtame PV. (1985). Statistical methods for agricultural workers. Indian Council of Agricultural Research, New Delhi *pp.* 186.

Passioura J. (2007). The drought environment: physical, biological and agricultural perspectives. *Journal of Experimental Botany* 58: 113-17.

Prasad MV, Wanjari V and Rethinam P. (2000).

Adoption pattern of the oil palm growers in Andhra Pradesh, India. International J of oil palm. 1 1&2); 51-58.

Murugesan P and Rethinam P (2000). Duration of oil palm bunch ripening under coastal climate of Andhra Pradesh, India. International J of oil palm. 1 1&2); 65-66.

Rajagopal V, Kasturibai KV, Kumar NS. (2005). Strategies for evolving drought tolerance in palms. National seminar on "Research and Development of Oil Palm in India" held during February 19-20, 2005 at Pedavegi, AP 16-20.

Rajendrakumar CSV, Reddy BVB, Reddy AR. (1994). Proline-protein interactions: protection of structural and functional integrity of M4 lactate dehydrogenase. *Biochemical. Biophysical Research Communications* 2: 957–63.

Rao BN, Suresh K, Behera SK, Ramachandrudu K, Manorama K. (2016). Irrigation management in oil palm (Technical Bulletin). ICAR-IIOPR, Pedavegi, Andhra Pradesh.

Rao KK. (2009). Effect of different methods of irrigation and nutrient requirement on yield of oil palm. *International Journal of Oil Palm Res* 6(1): 31-34.

Reddy AR, Chaitanya KV, Vivekanandan M. (2004). Drought-induced responses of photosynthesis and antioxidant metabolism in higher plants. *Journal of Plant Physiology* 161: 1189–1202.

Sairam RK, Rao KV Srivastava GC. (2002). Differential response of wheat genotypes to long term salinity stress in relation to oxidative stress, antioxidant activity and osmolyte concentration. *Plant Science* 163: 1037-1046.

Sanjeevreddi G, Patil DR, Maheshwarappa HP, Arulraj S, Mastan Reddy BG, Chandravathi B. (2014). Evaluation of African oil palm germplasm for drought tolerance. *Journal of Plantation Crops* 42(2): 170-74.

Sun C, Cao H, Shao H, Lei X, Xiao Y. (2011). Growth and physiological responses to water and nutrient stress in oil palm. *African Journal Biotechnology* 10(51): 10465-10471.

Szabados L, Savoure A. (2009). Proline: a multifunctional amino acid. *Trends Plant Science* 2:89-97.

Zhu XC, Sun ZM, Tao YQ, Gao WH, Huang QA, Cang ZW, Zhou XW. (2008). Introduction of prior variety of *Elaeis guineensis* from Malaysia. *Guangdong Forest Science Technology* 24: 84-86.