PLANT SCIENCE TODAY
Vol 13(2): 1-9
https://doi.org/10.14719/pst.9912

eISSN 2348-1900

RESEARCH ARTICLE

Assessment of environmental and biological factors influencing oil palm productivity decline

Senesie Swaray[1,2], Mohd Rafii Yusop[2], Momodu Jalloh[1,2*], Ansumana Joseph Musa[3], Mohamed Sesay[4] & Sheku Alhaji Koroma[5]

[1]Department of Agronomy, Faculty of Development Agriculture and Natural Resources Management, Eastern Technical University of Sierra Leone, Kenema, Sierra Leone
[2]Department of Crop Science, Faculty of Agriculture, Universiti Putra Malaysia, Serdang 43400 Selangor, Malaysia
[3]Department of Agribusiness, Faculty of Development Agriculture and Natural Resources Management, Eastern Technical Universityof Sierra Leon, Kenema, Sierra Leone
[4] Department of Mechanical and Production, Faculty of Engineering and Innovation, Eastern Technical University of Sierra Leone, Kenema, Sierra Leone
[5]Department of Agricultural Extension and Rural Sociology, Faculty of Development Agriculture and Natural Resources Management, Eastern Technical University of Sierra Leone, Kenema, Sierra Leone

*Correspondence email - mojalloh@etusl.edu.sl

Received: 08 June 2025; Accepted: 15 December 2025; Available online: Version 1.0: 22 March 2026; Version 2.0: 01 April 2026

Cite this article: Swaray S, Yusop MR, Jalloh M, Musa AJ, Sesay M, Koroma SA. Assessment of environmental and biological factors influencing oil palm productivity decline. Plant Science Today. 2026; 13(2): 1-9. https://doi.org/10.14719/pst.9912

Abstract

This study assessed environmental and biological factors influencing oil palm fruit set and yield decline. This study was conducted in Malaysia, Teluk Intan, Perak State, at the Malaysian Palm Oil Board (MPOB) Research Station during February 2019 to January 2020. The optimal oil palm fruit set is continuously declining, attributed to genetic origins, inflorescence sex ratio, pollinator insect (*Elaeidobius kamerunicus* Faust) and environmental factors (rainfall, field temperature, wind velocity, evaporation rate and sunshine duration). This study was conducted to investigate the most influential factor responsible for the decline in oil palm fruit set. The analysed results showed that oil to bunch was the highest contributor to oil yield, followed by mesocarp to fruit and fresh fruit bunch. The novelty of this study as a unique contribution to the oil palm industry primarily identified *E. kamerunicus* as the most influential biological factor in fruit set success, followed by wind velocity and field temperature, especially in older or taller palms with reduced male inflorescence. These findings can be used to develop strategies to combat declining oil palm fruit setting and low oil yield.

Keywords: decline; *Elaeidobius kamerunicus*; environmental factors; fruit set; yield traits

Introduction

The African palm (*Elaeis guineensis* Jacq.) is one of Malaysia's most important industrial perennial crops that has a long history and generates significant amounts of revenue (1). Large-scale oil palm cultivation is thought to have been concentrated in Southeast Asia, primarily in Indonesia, Malaysia and Thailand. Malaysia is the worlds' second-largest producer and exporter of palm oil, after Indonesia (2). China and India were the top importers (3). The need for vegetable oil is still increasing due to the growing world population. High-yielding tenera is the best material for commercial oil palm planting in Southeast Asia. Even with the possibility of higher production, efforts are always made to increase it; one strategy for addressing poor yield is to enhance agricultural yield features (4).

Malaysia's' economy benefited greatly from oil palm and the country gained international recognition for its oil palm research and development. Despite its progressively dropping yield, it continues to be a major driver of Malaysia's' economy. To meet the increasing needs of a world population that is only becoming bigger, scientists and governments have launched several projects and attempts to increase oil supply, including gathering, assessing, using and conserving genetic resources (5). Different series of oil palm planting materials that are currently in use were developed with a variety of breeding goals in mind, all geared at increasing oil yield.

Elite planting materials are essential to any increase in crop productivity. Therefore, breeding efforts should aim to use planting materials that are resistant to common pests and diseases and have a high-yielding capacity. In light of this, the MPOB has used selective breeding to create a variety of oil palm planting materials using germplasm around the world. The oil yield of oil palm remains variable despite improvement efforts to increase its yield potential. Inadequate pollinators during male inflorescence anthesis are one of the variables contributing to low output (6). Production of palm oil depends on the pollination of oil palm pollen (7, 8). Male inflorescence production needs to be suitable for the provision of pollen and breeding sites for pollinating insects. This can only be achieved by growing the appropriate genotype planting materials. Pollination is a crucial component for the yield improvement of oil palm inflorescences, alternating between male and female forms. There is a considerable variation in time spent on each stage due to genetic diversity and climatic factors.

Consequently, *E. kamerunicus*, has gained recognition as one of the key pollinators in oil palm plantations (9). To prevent inadequate pollination and low fruit set development, palm plantations should maintain the population density and efficiency of this pollinator. Research has demonstrated that the genetic origins of oil palm had an impact on the diminishing fruit set (10). Similarly, it is worth observing that the decline in *E. kamerunicus* population is region-specific to all tropical regions, including Malaysia and other nearby nations that produce oil palm in the Southeast Asia region. Research has reported that to enhance pollination and fruit set of *E. guineensis*, *E. kamerunicus* was key in all tropical regions where oil palm has been grown since the late 20th century (11). *Elaeidobius kamerunicus* resides, feeds and reproduces mainly on the male inflorescences of oil palms (12, 13). An abundance of oil palm male inflorescences increases the population abundance of this pollinator. However, changes in the climate may have an impact on the number of pollinating weevils and the development of fruit. High rainfall and wind speeds and extended sunny periods may cause the oil palm pollinator weevil population to decline (1, 13). Similarly, a high sex ratio will reduce the number of weevil breeding grounds, which will result in a low weevil population. A higher sex ratio indicates a higher occurrence of female inflorescences in oil palm. Nonetheless, a high sex ratio also indicates a relatively low density of oil palm male inflorescences (14).

Changes in atmospheric conditions may also result in diverse reactions in oil palm, especially at the onset of fruit setting. In Southeast Asia, a 10–30 % decline in oil palm yield was reported due to the increasing incidence of drought (15). Therefore, to get an average yield, the palm tree needs an annual rainfall of 1500–2000 mm spread evenly, with minimum and maximum temperatures of 22–24 °C and 29–33 °C, respectively (16, 17). Oil palm yield may further decline due to predictable water stress and temperature increases (18, 19). It may even put the oil palm-producing nations of Southeast Asia in unfavourable conditions for the growth and development of palm oil (20). This study aims to identify the main causes of the reduction in oil palm fruit set and oil yield, with an emphasis on the roles played by *E. kamerunicus* pollinator populations and environmental factors.

Materials and Methods

The 24 D × P progenies developed by the MPOB through a biparental breeding design served as planting materials for this study. The progenies used comprised four male pisiferas and six female duras. However, the 24 D × P progenies were used to evaluate yield variability and pollination traits across genotypes.

Study location and experimental design

The MPOB Research Station in Teluk Intan, Perak State, was the site for this study. In September 2008, MPOB planted palms on 12.06 hectares on deep peat soil using an Independent Complete Randomised Design (ICRD) in a triangular planting distance of 8.5 m, but this research was carried out in February 2019 to January 2020. The biparental progenies' performance was assessed using the standard technique for bunch yield and yield characters. A total of 1520 palms were used and a structured random selection of palms per progeny for the bunch analysis and fruit composition (21).

A structured random selection of 20 palms for each progeny, making a total of 480 palms were nominated for sex ratio and fruit set data collection and a total of 288 palms from the experimental palm densities randomly selected following the methods to determine the population density and pollination efficacy of *E. kamerunicus* in oil palms were assessed using the same experimental design (22, 23). To categorise the opening and functionality of the male inflorescence, a standard technique was used (22).

Procedures and data collection

The following information was gathered about yield, fruit bunch quality features, Inflorescence Sex Ratio (ISR), Fruit Set Ratio (FSR), population size of *E. kamerunicus* (EK) and climate data: data on yield and yield traits, such as Fresh Fruit Bunch (FFB), Bunch Number (BNO) and Average Bunch Weight (ABW), were gathered (21, 24). On the other hand, the Fruit to Bunch ratio (FTB), Fertile Fruit to Bunch (FFTB), Mesocarp to Fruit (MTF), Oil to Bunch (OTB) and Palm Oil Yield (POY) procedures on fruit quality attributes were done (25, 26). To determine the traits that mostly influence high oil output and the variables that have the most impact on oil palm fruit setting, used POY as the dependent variable and other traits as the independent variables. Data on bunch yield and yield traits were collected at regular harvesting intervals of two weeks. The Fruit Set (FS) and Sex Ratio (SR) data were collected quarterly for four consecutive rounds. Data on the population density of *E. kamerunicus* among the 24 D × P progenies were collected for 12 months at monthly intervals (23).

Climatic data on Average Rainfall (ARF mm), Average Field Temperature (AFT °C), average solar radiation (ASH W/m^2), Average Evaporation (AER mm) and Average Wind Velocity (AWV km/hr) were collected from the Meteorological Department at a local Experimental Research Station, commencing from February 2019 to January 2020. Variables identified for assessing the primary factors influencing high oil yield and FS decline were chosen based on their individual impacts on high FS and oil yield.

Stepwise Regression-Forward (SWR-F) procedure and link on major factor determining traits

The following linear equation was employed at two distinct stages to identify the primary contributor to oil yield and the principal factor in the decline of the oil palm fruit set, using version 9.4 of the Statistical Analysis System (SAS) of the Generalized Linear Model (GLM) on provincial climate data, selected traits from the 24 biparental progenies of oil palm including ISR, FSR and *E. kamerunicus*.

$$Y = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \beta_5X_5 + \beta_6X_6 + \beta_7X_7 \quad \text{(Eqn. 1)}$$

To determine the most beneficial and contributing component potentials for high POY and to identify the main causes of the fall in oil palm fruit set, this study used Pearsons' correlation and stepwise-forward regression techniques. The forward selection method was used because the number of variables used was smaller in number. Research indicates that with a small subset size of all possible regressions, the forward selection procedure tended to agree with the results from the backward selection procedure. The independent variables and dependent variables were distinguished with clarity and the use of stepwise regression was essential. The forward selection method was used because the variables used were smaller in number and the goal of stepwise-forward regression is to include only those traits in the regression equation that significantly contribute to fluctuations in the dependent variable. Traits were added methodically one at a time from an initially empty equation. Whereas the backward selection method can only be used with a large number of variables. Nonetheless, the Mallows $C_{(p)}$ (critical/complexity parameter), statistical method described was used to choose the best-fitting model for factors that most significantly contributed to the high yield of palm oil and to choose the most contributing factor to low FS (27, 28). The most helpful explanatory variable that met the required condition ($p < 0.05$) was chosen from the explanatory variables (X_k) in the selection process, which was included in the final regression model. The model procedures proposed were followed (28).

$$Y = \beta_0 + \beta_1 X_1 + \ldots \beta_K X_K \quad \text{(Eqn. 2)}$$

Where,

Y = dependent variable; β_0= Intercept; β_1= Slope; k = Explanatory variables; X_1= Independent variable

The regressors include one response variable (POY) as against seven explanatory variables (FFB, BNO, ABW, FTB, FFTB, MTF and OTB), which were used in the model:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 \quad \text{(Eqn. 3)}$$

Where, Y = POY; β_o = Intercept; β_1= Slope; X_1= FFB; β_2 = Slope; X_2 = BNO; β_3= Slope; X_3= ABW; β_4= Slope; X_4= FTB; β_5= Slope; X_5= FFTB; β_6 = Slope; X_6= MTF; β_7= Slope and X_7= OTB

Results and Discussion

Correlation and stepwise regression

Numerous studies have examined the relationship between the diversity and abundance of weevils and their pollination effectiveness on African oil palm in connection to low FFB and palm oil production in various regions (23). Therefore, the expected model step one $Y = \beta_0 + \beta_1 X_1 + \beta_K X_K$ indicated that the first stage (Table 1) showed a significant association between POY and OTB (pr > F = < 0.01) with an R-Squared of 0.6476; the regressions' intercept and coefficient were 2.124 and -8.220, respectively. Thus, $Y = -8.220 + 2.124X_7$ could be the relationship model for POY and OTB in this investigation. The regression effect indicated that the regression line could account for 64.76 % of the correlation between POY and OTB. The association between POY and OTB was not equal to zero, as shown by the regressions' intercept and coefficient. It is believed that the stepwise regression summary is an essential part of the analysis. Several studies concentrated on specific guiding concepts for selecting halting rules for stepwise regression (29).

However, α = 0.25 and α = 0.10 were suggested as cut-off points for forward and backward selection procedures, respectively (30). The suggestion for a forward selection procedure cut-off point (α = 0.25) was further recommended (31). The present study used a default cut-off point for model admission and none of the independent variables under consideration met the 0.05 significance threshold needed for model admission by default. At this point, stepwise regression forward was terminated (Table 1). Moreover, steps that exhibit significant correlations with the independent variable or variables' contribution to the affiliation are validated (29).

It is believed that genetic variations are important in plant breeding programs, such as the oil palm, they allow additional genes to be incorporated into the oil palms' limited genetic base through introgression. Therefore, the expected model step two of $Y = -\beta_0 + \beta_7 X_7 + \beta_K X_K$, implied that with an R^2 of 0.6904, the ANOVA of the second step, which examined MTF and OTB, shows a highly significant association with POY. The regression line at 69.04 % may help to understand the correlation between these variables. Consequently, there was a highly significant correlation between the intercept of -35.898 and the MTF and OTB regression coefficients of 0.496 and 1.658, respectively. Thus, $Y = -35.898 + 0.496X_6 + 1.658X_7$ could be the relationship model between POY with MTF and OTB. These two variables (MTF and OTB) are key traits for high palm oil productivity; thus, oil palms with such qualities should be selected for future breeding programs.

Similarly, OTBs' influence on POY was 64.8 %, as indicated by the partial R-Square of 0.648, considering that just OTB was included in the studys' initial phase. In the second step of the investigation, MTF and OTB were also considered, indicating a 4.3 % contribution of MTF to POY, conditional on other variables. However, the degree of ripeness of the fruit used to make palm oil has a significant impact on the quality of the finished product (32).

Equally so, the expected model step three of $Y = -\beta_0 + \beta_6 X_6 + \beta_7 X_7 + \beta_k X_k$, similarly, showed that the third phase of the study looked at FFB, MTF and OTB. A partial R-Square of 0.018 in the results indicated a 1.8 % influence of FFB on POY. The combined study of FFB, MTF and OTB showed a highly significant correlation between POY and variables, with an R-Square of 0.7082 (Table 1). However, the correlation at 70.82 % may be explained by the regression line. The correlation coefficients for FFB (0.049), MTF (0.406) and OTB (1.615), as well as the relationships' intercept (-35.116), were all statistically significant, with OTB being the most significant trait. The relationship between POY and FFB, MTF and OTB is represented by the relationship model Y = -35.116 + 0.049X1 + 0.406X6 + 1.615X7.

Also, the expected model step four $Y = -\beta_0 + \beta_1 X_1 + \beta_6 X_6 + \beta_7 X_7 + \beta_k X_k$, with an R-Square of 0.7144 for the variables BNO, FFB, MTF and OTB combined, indicated a strong association between POY and these variables. According to the analysis, 71.44 % of the relationship could be explained by the regression line. The connection between POY and BON was not significant, but the intercept of -32.193 and the regression coefficients of FFB and MTB were significant and OTB was considered to be extremely significant (Table 1). The relationship between POY, FFB, BNO, MTF and OTB was modelled using the regression equation:

$$Y = -32.193 + 0.075X_1 - 0.303X_3 + 0.382X_6 + 1.630X_7$$

Additionally, the partial R^2 were 0.006 and 0.002 for the fourth and fifth steps of the variables (FFB, BNO, MTF and OTB) and (FFB, BNO, FFTB, MTF and OTB) that were evaluated jointly. However, the analysis revealed that BNO had a 0.6 % influence on POY, while FFTB had a 0.2 % effect. Since BNO and FFTB with POY did not show any meaningful link, it is advised that they be left out of the final model. As a result, the elimination of these factors in steps four and five reduced the connection for POY by 0.6 % and 0.2 %, respectively. According to a previous study, the Mallows $C_{(p)}$ (critical/complexity parameter) statistic with the lowest $C_{(p)}$ should be used to select the best-fitting model (28). Consequently, step three was considered the most appropriate model for POY since it had the lowest C(p) of 2.510 and the $Y = -35.116 + 0.049X_1 + 0.406X_6 + 1.615X_7$.

Likewise, the expected model in step five of $Y = -\beta_0 + \beta_1 X_1 - \beta_3 X_3 + \beta_6 X_6 \ \beta_6 X_7 + \beta_k X_k$ had an R-Square of 0.7162. Model 5 demonstrates that POY recorded a highly significant link with FFB, BNO, FFTB, MTF and OTB. This suggests that 71.62 % of the affiliation may be explained by the regression line. Indicating that the combination of such traits increases POY productivity and any oil palm diversity with such traits should be selected for future breeding programs. Therefore, the intercept and regression coefficient for every variable in Table 1 showed a substantial association between POY and these factors. In general, though, POYs' relationship to BON

Table 1. Analysis of variance and parameter estimation for identifying main causative traits in palm oil yield

Step 1	**Variable OTB entered: R-square = 0.6476 and $C_{(p)}$ = 15.4185**				
Source	**DF**	**SS**	**MS**	**F value**	**Pr > F**
Model	1	4566.483	4566.483	156.23	<.0001
Error	85	2484.531	29.210		
C/total	86	7051.014	4566.483		
Variable	Parameter estimate	Std error	SS	F value	Pr > F
Intercept	-8.220	3.824	135.045	4.62	0.0344
OTB	2.124	0.170	4566.483	156.23	<.0001
Step 2	**Variable MTF entered: R-square = 0.6904 and $C_{(p)}$ = 5.4602**				
Source	**DF**	**SS**	**MS**	**F value**	**Pr > F**
Model	2	4868.365	2434.182	93.68	<.0001
Error	84	2182.650	25.984		
C/total	86	7051.014			
Variable	Parameter estimate	Std error	SS	F value	Pr > F
Intercept	-35.898	8.885	424.183	16.32	0.0001
MTF	0.496	0.145	301.881	11.62	0.0010
OTB	1.658	0.211	1610.069	61.96	<.0001
Step 3	**Variable FFB entered: R-square = 0.7082 and $C_{(p)}$ = 2.5098**				
Source	**DF**	**SS**	**MS**	**F value**	**Pr > F**
Model	3	4993.336	1664.445	67.14	<.0001
Error	83	2057.678	24.791		
C/total	86	7051.014			
Variable	Parameter estimate	Std error	SS	F value	Pr > F
Intercept	-35.116	8.686	405.254	16.35	0.0001
FFB	0.049	0.022	124.972	5.04	0.0274
MTF	0.406	0.148	187.370	7.56	0.0073
OTB	1.615	0.207	1514.194	61.08	<.0001
Step 4	**Variable BNO entered: R-square = 0.7144 and $C_{(p)}$ = 2.7707**				
Source	**DF**	**SS**	**MS**	**F value**	**Pr > F**
Model	4	5037.237	1259.309	51.28	<.0001
Error	82	2013.777	24.558		
C/total	86	7051.014			
Variable	Parameter estimate	Std error	SS	F value	Pr > F
Intercept	-32.193	8.917	320.123	13.04	0.0005
FFB	0.075	0.029	161.872	6.59	0.0121
BNO	-0.303	0.227	43.901	1.79	0.1849
MTF	0.382	0.148	164.221	6.69	0.0115
OTB	1.630	0.206	1537.705	62.61	<.0001
Step 5	**Variable FFTB entered: R-square = 0.7162 and $C_{(p)}$ = 4.2733**				
Source	**DF**	**SS**	**MS**	**F value**	**Pr > F**
Model	5	5049.795	1009.959	40.88	<.0001
Error	81	2001.219	24.706		
C/total	86	7051.014			
Variable	Parameter estimate	Std error	SS	F value	Pr > F
Intercept	-37.159	11.336	265.491	10.75	0.0015
FFB	0.076	0.029	165.652	6.70	0.0114
BNO	-0.308	0.228	45.227	1.83	0.1798
FFTB	0.09	0.126	12.558	0.51	0.4779
MTF	0.426	0.161	174.049	7.04	0.0096
OTB	1.483	0.292	635.931	25.74	<.0001

Summary of forward selection

Step	**Variable entered**	**Number vars in**	**partial R-square**	**Model R-square**	**$C_{(p)}$**	**F value**	**Pr > F**
1	x_7	1	0.648	0.648	15.419	156.23	<.0001
2	x_6x_7	2	0.043	0.690	5.460	11.62	0.0010
3	$x_1x_6x_7$	3	0.018	0.708	2.510	5.04	0.0274
4	$x_3x_1x_6x_7$	4	0.006	0.714	2.771	1.79	0.1849
5	$x_5x_3x_1x_6x_7$	5	0.002	0.716	4.273	0.51	0.4779

Note: DF = degree of freedom, C/total = corrected total, SS = sum of squares, MS = mean square, FFB = fresh fruit bunch, BNO = bunch number, FFTB = fertile fruit to bunch, MTF = mesocarp to fruit, OTB = oil to bunch, $C_{(p)}$ = critical/complexity parameter, vars = variables.

and FFTB was not noteworthy. The POY relationship, then, may be expressed as follows, given the variables examined: $Y = -37.159 + 0.076X_1 – 0.308X_3 + 0.09X_5 + 0.0426X_6 + 1.483X_7$

On the contrary, the expected model in step six of $Y = -\beta_0 + \beta_1X_1 - \beta_3X_3 + \beta_5X_5 + \beta_6X_6 + \beta_7X_7 + \beta_kX_k$ the added variable was not included in the model because the cut-off point requirement was not met.

The correlation coefficient was used to further validate the results obtained from the stepwise regression forward analysis. It revealed that POY had a positive and highly significant relationship with OTB, MTF, FTB, FFTB and FFB, while POY recorded a positive and significant relationship with ABW and BNO, respectively. This means that POY had a positive moderate relationship with MTF ($r = 0.67978$; df = 3, 23; $p < 0.0001$), a positive relationship with FFTB ($r = 0.48287$; df = 3, 23; $p < 0.0001$) and a positive weak relationship with FFB ($r = 0.43964$; df = 3, 23; $p < 0.0001$) and a strong positive and significant relationship with OTB ($r = 0.80476$; df = 3, 23; $p < 0.0001$).

Key oil-contributing traits in oil palm are FFB, MTF and OTB. Research has demonstrated that declines in oil (21.2–18.8 %) and kernel (4.7–3.5 %) extraction rates occurred between 1993 and 1996 (33). Malaysia's average oil extraction rate was less than 20 %. Climate variations could affect oil palm FS, which could be caused by a decrease in pollen availability and some environmental problems (34). Due to the rising temperatures, degraded land and heightened susceptibility to pests and diseases, climate change may have a substantial impact on productivity (35). Crops' tolerance to climate change may degrade between 2070 and 2100, endangering long-term viability and production of palm oil could fall precipitously after 2050 due to more inappropriate climatic circumstances (36).

Numerous investigations have been conducted to identify and categorise the oil palm fruits' maturation stage to enhance quality (32). Oil palm FFB and oil production per hectare can be directly improved by the higher density, as long as the compact palms retain similar levels of production. However, the trait introgression process in oil palm breeding is delayed because it is a perennial crop with a phenotyping time of at least ten years (37). However, the climate has an impact on the growth and development of oil palm fruit and reduces the significance of other production parameters (38). With diminishing yields and more obvious difficulties, the effect of climate change on palm oil production has grown to be a significant worry (37). Natural rainfall combined with irrigation had a significant impact on oil palm FFB productivity (39). Based on the computed estimated results published, the FFB yield gap occurred among the oil palm genotypes investigated for FFB yield performance (40). The current studys' results clearly demonstrated a positive association between POY and OTB, with moderate relationships found with MTF and FFB. Consequently, it might be advised that future breeding initiatives choose genetic origins and their offspring with high OTB values for better oil yield achievement.

Oil palm breeding programs heavily rely on an understanding of the genetic structure of various vegetative attributes, yield traits and yield component characters (26). The primary objective of oil palm production is to increase oil yield and quality, which can be achieved through genetic improvement of specific traits through breeding programs (40). In order to improve oil productivity through breeding, factors that significantly and directly affect oil yield must be assessed (41). The main cause of the drop in oil palm FS was identified based on the process outlined through the best-fitting model (28). The associations intercept and regression coefficient indicated that it was significant for reaching a high oil yield because the relationship did not equal zero. FS was influenced by the combined performance of PD/EK, AWV, AFT and ISR. The ISR was eliminated from the final model by using the standard protocol (29). However, a 0.38 % decrease in the FS was explained by the final models' elimination of the ISR. Nonetheless, the Mallows $C_{(p)}$ Statistical method described was used to choose the best-fitting model. Therefore, when determining the key basis causing the drop in the oil palm FS, step three, which had the lowest $C_{(p)}$, was deemed to be the best-fitting model (28).

Major factor that determines the decline in oil palm fruit set

The ISR, population density of *E. kamerunicus* (PD/EK), annual AWV, annual Average Sunshine Hour (ASH), annual AER, annual ARF and annual average temperature (AFT) were among the seven independent variables measured in model II of the regression models. Therefore, the one dependent variable used was FSR with Eqn. 2 and 3,

$$Y = \beta_0 + \beta_1X_1 + \beta_2X_2 + \ldots\beta_kX_k$$

$$Y = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \beta_5X_5 + \beta_6X_6 + \beta_7X_7$$

Therefore, the expected model in step one equation of $Y = \beta_0 + \beta_kX_{7k}$, in Table 2 presented an analysis of variance together with additional step parameters. The PD/EK was the first variable to enter the model, suggesting a substantial link between PD/EK and FSR. Thus, the regression line with an intercept of 42.814 and a regression coefficient of 0.007 may explain 8.54 % of the relationship between these two variables and the model for the association between FSR and PD/EK was $Y = 42.814 + 0.07X_2$. Since *E. kamerunicus* was the first variable to be included in the regression model, it was assumed that this was the primary cause of the decline in the oil palm FS (33). The population density of *E. kamerunicus* is declining due to low production of male inflorescences, environmental factors, primarily rainfall, parasitic nematodes and a range of 10–20 % of seasonal poor fruit sets (33). Poor fruit sets and insufficient pollination have been documented in several states, particularly in the Northeastern regions of India and Malaysia, which is not an exception (42). With all these indicators, given that the ratio of female to total inflorescences within a cluster of palms determines an oil palm plants' sex, it follows that those climatic factors, such as water scarcity, which raises the ratio of male inflorescences, have the greatest influence on this determination. Practically, the oil palm SR varies throughout nations with varying climates because the wet or dry season restricts or increases the activity of pollinators, which in turn impacts pollen dispersal and fruit output (33). However, the social implications are just as important as the economic and environmental ones and the reduction in yields and erratic weather make it harder for smallholder farmers to sustain their livelihoods (43). Income instability, diminished palm oil food security and heightened competition for resources and land can all result from unstable productivity (36).

Moreover, the anticipated model step two of $Y = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_kX_k$, implying that PD/EK and AWV were included in the model during the second stage, suggests a substantial link between these two variables and FSR. Consequently, the regression line could accurately identify 9.73 % of the relationship. Regression coefficients of 0.008 (PD/EK) and 0.028 (AWV) for this association proved to be significant, indicating that the relationship was not equal to zero, whereas the intercept value of 14.988 was not significant. The relationship model can be expressed as, for FSR, PD/EK and A/WV, as

Table 2. Estimates of parameters for determining important factors in oil palm fruit set decline

Step 1	**Variable PD/EK entered: R-square = 0.0854 and $C_{(p)}$ = 7.8031**				
Source	**DF**	**SS**	**MS**	**F value**	**Pr > F**
Model	1	1938.87224	1938.87224	32.32	<.0001
Error	346	20757	59.99204		
C/total	347	22696			
Variable	Parameter estimate	Std error	Type II SS	F value	Pr > F
Intercept	42.81396	1.21132	74946	1249.26	<.0001
PD/EK	0.00664	0.00117	1938.87224	32.32	<.0001
Step 2	**Variable AWV entered: R-square = 0.0973 and $C_{(p)}$ = 5.2312**				
Source	**DF**	**SS**	**MS**	**F value**	**Pr > F**
Model	2	2208.62419	1104.31210	18.60	<.0001
Error	345	20487	59.38404		
C/total	347	22696			
Variable	Parameter estimate	Std error	SS	F value	Pr > F
Intercept	14.98846	13.11107	77.60826	1.31	0.2538
PD/EK	0.00830	0.00140	2091.19815	35.21	<.0001
AWV	0.02756	0.01293	269.75195	4.54	0.0338
Step 3	**Variable aft entered: R-square = 0.1067 and $C_{(p)}$ = 3.6123**				
Source	**DF**	**SS**	**MS**	**F value**	**Pr > F**
Model	3	2422.14983	807.38328	13.70	<.0001
Error	344	20274	58.93595		
C/total	347	22696			
Variable	Parameter estimate	Std error	SS	F value	Pr > F
Intercept	46.29342	21.00229	286.34227	4.86	0.0282
PD/EK	0.01020	0.00171	2088.30714	35.43	<.0001
AWV	0.06715	0.02446	444.00913	7.53	0.0064
AFT	-2.46799	1.29661	213.52564	3.62	0.0578
Step 4	**Variable ISR entered: R-square = 0.1106 and C(p) = 4.1364**				
Source	**DF**	**SS**	**MS**	**F value**	**Pr > F**
Model	4	2509.23173	627.30793	10.66	<.0001
Error	343	20187	58.85389		
C/total	347	22696			
Variable	Parameter estimate	Std error	SS	F value	Pr > F
Intercept	54.17985	21.96627	358.04559	6.08	0.0141
ISR	-0.03318	0.02727	87.08190	1.48	0.2247
PD/EK	0.00975	0.00175	1825.10617	31.01	<.0001
AWV	0.06647	0.02445	434.85241	7.39	0.0069
AFT	-2.60990	1.30095	236.86628	4.02	0.0456

Summary of forward selection

Step	**Variable entered**	**Number vars in**	**Partial R-square**	**Model R-square**	**$C_{(p)}$**	**F value**	**Pr > F**
1	X_2	1	0.0854	0.0854	7.8031	32.32	<.0001
2	X_3X_2	2	0.0119	0.0973	5.2312	4.54	0.0338
3	$X_7X_3X_2$	3	0.0094	0.1067	3.6123	3.62	0.0578
4	$X_1X_7X_3X_2$	4	0.0038	0.1106	4.1364	1.48	0.2247

DF = degree of freedom, C/total = corrected total, SS = sum of squares, MS = mean square, $C_{(p)}$ = critical/complexity parameter, vars = variables, ISR = inflorescence sex ratio, PD/EK = population force of *Elaeidobius kamerunicus*, AWV = annual wind velocity, AFT = annual temperature.

$Y = 14.988 + 0.008X_2 + 0.028X_3$. Yet the association between PD/EK and AWV suggested that, during anthesis, the population density of *E. kamerunicus* would increase with decreasing wind velocity and field temperature. Conversely, the lower the PD/EK, the higher the wind velocity or field temperature during the anthesis period. Therefore, a high PD/EK in palm farms indicated a higher oil palm output (33). Consequently, it is impossible to overstate the significance of this noteworthy pollinator weevil.

Also, the expected model step three of $Y = β_0 + β_2X_2 + β_3X_3 + β_kX_k$ in the third phase, a significant correlation was found between FSR and PF/EK, A/WV and A-T. The regression line could account for 10.67 % of this link. These variables' intercepts and regression coefficients were significant and the model for the association between FSR, PD/EK, AWV and AFT was $Y = 46.293 + 0.01X_2 + 0.672X_3 – 2.468X_7$. The PD/EK, AWV, AFT and ISR collectively demonstrated a significant relationship with FSR in the fourth step of the study. Consequently, the regression line could define 11.06 % of their relationship. Therefore, all of the regression coefficients except for ISR—0.033(ISR), 0.01(PD/EK), 0.O66(AWV) and -2.61(AFT) and the intercept of 54.18 were significant for this relationship. So, the following factors should be used to represent the relationship between FSR and SR, PD/EK, AWV and AFT, with an equation of $Y = 54.18 -0.033X_1 + 0.01X_2 + 0.066X_3 -2.61X_7$. This indicated that the contributions of SR, PD/EK, AWV and AFT in oil palm plantations are key contributors in the increase of oil palm FS, especially SR and PD/EK.

Moreover, the anticipated model step four $Y = β_0 + + β_2X_2 + β_3X_3 - β_7X_7 + β_kX_k$, in the fourth step of the stepwise regression forward process, was automatically ended. Each explanatory variables' contribution to the FS was noted. The analysis summary of this study is presented in Table 2. Therefore, only PD/EK was included in the first step of the forward stepwise regression equation and its partial R -Square of 0.0854 meant that the PD/EK had an 8.54 % effect on the FS. The PD/EK and AWV measurements taken jointly in the second stage produced a partial R-Square of 0.0119. This implied that there was a 1.19 % impact on the FS. When AWV, AFT and PD/EK entered the third phase, the partial R-Square gain was 0.0094, meaning that the combined effect on the FS was 0.94 %. Furthermore, it was noted that the combination of PD/EK, AWV, AFT and ISR in the fourth step of the analysis did not significantly affect the FS, with a partial R-Square of 0.0038, indicating a 0.38 % influence. Step three, which used a model of Y = 46.293 + 0.01X2 + 0.672X3 – 2.468X7, produced the lowest $C_{(p)}$ of 3.6123.

Similarly, a correlation analysis was carried out to estimate the relationship between variables for further validation of the result obtained. Therefore, a correlation can either be positive or negative in terms of the phenotypic relationship that develops between two characters. Pearsons' correlation was used to estimate the phenotypic correlations of the traits at $p ≤ 0.01$ high significance levels and $p ≤ 0.05$ significance levels. So, to evaluate the correlation coefficient (r), the following relationships were considered, where ($0.90 < r = 1$) is a perfect relationship, ($0.75 ≤ r ≤ 0.90$) is a strong relationship, ($0.5 ≤ r ≤ 0.75$) is a moderate relationship and ($r < 0.50$) as weak relationship (44, 45). Where, *p* is the probability value, df is the degree of freedom for both replications of oil palm progenies and r is the correlation value.

The results of the investigation indicated that FSR and the PDEK (r = 0.29; df = 3, 23; *p* = 0.0001) had a weak positive correlation in this study. The ISR found a weak positive significant link with AER (r = -0.21; df = 3, 23; *p* = 0.0001) and ARF, (r = -0.23; df = 3, 23; *p* = 0.0001) but a weak negative significant relationship with PD/EK (r = -0.25; df = 3, 23; *p* = 0.0001), ASH (r = -0.25; df = 3, 23; *p* = 0.0001) and AFT (r = -0.17; df = 3, 23; *p* = 0.0019). As a result, during a year with wet and humid weather, the ratio changes are minimal for tropical nations like Indonesia and Malaysia, which produce the most palm oil. However, in arid areas like West Africa, the SRs differ significantly (33, 46).

However, a significant link between ISR and AWV suggests that wind velocity had no bearing on the calculation of ISR in oil palm. Similarly, the result showed that PD/EK had a weak, significantly negative association with AFT (r = -0.11; df = 3, 23; *p* = 0.0320) and a negative, moderately significant link with AWV (r = -0.57; df = 3, 23; *p* = 0.0001). Whereas, a weak negative non-significant relationship was found between PD/EK and ASH (r = -0.02; df = 3, 23; *p* = 0.6790) and ARF (r = -0.03; df = 3, 23; *p* = 0.0001), PD/EK was found to have a weak negative significant link with AER (r = -0.31; df = 3, 23; *p* = 0.0001). It was noticed that AWV had a moderate positive relationship with ASH (r = 0.66; df = 3, 23; *p* = 0.0001). Moreover, AWV had a strong relationship with AFT (r = 0.77; df = 3, 23; *p* = 0.0001), whereas ASH similarly recorded a perfect positive correlation with AFT (r = 0.97; df = 3, 23; *P* = 0.0001) in this study.

Conclusion

The results showed that three regressors in step three produced the best-fitting model for high POY. The first variable to enter the model was OTB, which was followed by MTF and FFB, suggesting that OTB was the most influential factor contributing to high oil productivity. The correlation results confirmed that POY and OTB had a substantial association, which was followed by MTF and FFB. Similarly, *E. kamerunicus* was the first regressor to match the model and it had a positive and statistically significant link with the oil palm FS, whereas the wind velocity was considered as the second major factor, followed by field temperature. Consequently, at stage three, the best-fitting model for identifying the primary cause of the drop in oil palm FS was attained. Based on the studys' findings, *E. kamerunicus* was found to be the primary factor responsible for the drop in FS, with wind velocity and field temperature coming in second and third, respectively. However, if used as a selection criterion in conjunction with the current conventional study and molecular studies, it may yield new data to support the researchs' current conclusions.

Acknowledgements

The authors are thankful to the Management staff and field workers of the MOPB at Teluk Intan, Research Station, Perak state, Malaysia, for their consent and help towards the realisation of this study. We are similarly obligated to the Universiti Putra Malaysia (UPM) as one of the learning and research institutes in Southeast Asia. The main author is beholden to the Sierra Leone Agricultural Research Institute (SLARI), Palm Oil Production Project in Sierra Leone (POPSLCB) and the Eastern Technical University (ETU-SL) for their support. All relevant contributors, including anonymous reviewers, are acknowledged for their contributions to the manuscript's quality.

Authors' contributions

MRY contributed to conceptualisation, study design, software implementation, formal analysis, supervision, manuscript review and authentication of the manuscript. SS contributed to conceptualisation, study design, conducting experiments, data collection, software implementation, formal analysis and writing the original draft of the manuscript. MJ contributed to software implementation, formal analysis, supervision, manuscript review and authentication of the manuscript. AJM contributed to supervision, manuscript review and authentication of the manuscript. MS contributed to supervision, manuscript review and authentication of the manuscript. SAK contributed to supervision, manuscript review and authentication of the manuscript. All authors read and approved the final version of the manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

References

1. Swaray S, Amiruddin MD, Rafii MY, Jamian S, Ismail MF, Yusuff O, et al. Impact of *Elaeidobius kamerunicus* population in F1 hybrid single-generation families of oil palm on Malaysia profound peat soil. Int J Environ Agric Biotechnol. 2022;7(3):1-15. https://doi.org/10.22161/ijeab.73.5
2. Kushairi A, Loh SK, Azman I, Hishamuddin E, Ong-Abdullah M, Izuddin ZBMN, et al. Oil palm economic performance in Malaysia and R&D progress in 2017. J Oil Palm Res. 2018;30(2):163-95.
3. Daniel W. Palm oil imports by country. Worlds' Top Exports; 2020
4. Zolkafli SH, Ting NC, Nik Mohd Sanusi NS, Ithnin M, Mayes S, Massawe F, et al. Comparison of quantitative trait loci associated with yield components in two commercial *Dura* × *Pisifera* breeding crosses. Euphytica. 2021;217(6):1-29. https://doi.org/10.1007/s10681-021-02825-9
5. Ahmad Malike F, Amiruddin MD, Yaakub Z, Marjuni M, Abdullah N, Abu Bakar NA, et al. Oil palm (*Elaeis* spp.) breeding in Malaysia. In: Al-Khayri JM, Jain SM, Johnson DV, editors. Advances in plant breeding strategies: industrial crops. Cham: Springer; 2019. p. 489-535 https://doi.org/10.1007/978-3-030-23265-8_13
6. Swaray S, Rafii MY, Amiruddin MD, Firdaus Ismail M, Jamian S, Jalloh M, et al. Assessment of oil palm pollinating weevil (*Elaeidobius kamerunicus*) population density in biparental *Dura* × *Pisifera* hybrids on deep peat soil in Perak State, Malaysia. Insects. 2021;12(3):221. https://doi.org/10.3390/insects12030221
7. Rao A, Suci R, Intan A, Rizkita RE, Ramadhani EP. Resource partitioning and different foraging behaviour as the basis for coexistence of *Thrips hawaiiensis* and *Elaeidobius kamerunicus* on oil palm (*Elaeis guineensis* Jacq.) flowers. J Ecol Nat Environ. 2013;5(5):59-63. https://doi.org/10.5897/JEN12.008
8. Soetopo D. Population of oil palm pollinator insect (*Elaeidobius kamerunicus*) at PTP Nusantara VIII Cisalak Baru, Rangkasbitung, Banten. IOP Conf Ser Earth Environ Sci. 2020;418:012045. https://doi.org/10.1088/1755-1315/418/1/012045
9. Nasir DM, Mamat NS, Muneim NAA, Ong-Abdullah M, Abd Latip NFB, Su S, et al. Morphometric analysis of the oil palm pollinating weevil, *Elaeidobius kamerunicus* (Faust, 1878) (Coleoptera: Curculionidae) from oil palm plantations in Malaysia. J Entomol Res Soc. 2020;22(3):275-91. https://doi.org/10.51963/jers.v22i3.1874
10. Swaray S, Amiruddin MD, Rafii MY, Jamian S, Ismail MF, Jalloh M, et al. Influence of parental *Dura* and *Pisifera* genetic origins on oil palm fruit set ratio and yield components in their D × P progenies. Agronomy. 2020;10(11):1793. https://doi.org/10.3390/agronomy10111793
11. Haran J, Abanda RFXN, Benoit L, Bakoumé C, Beaudoin-Ollivier L. Multilocus phylogeography of world populations of *Elaeidobius kamerunicus* (Coleoptera: Curculionidae), pollinator of the palm *Elaeis guineensis*. Bull Entomol Res. 2020;110(5):654-62. https://doi.org/10.1017/S0007485320000218
12. Luqman HA, Noor N, Dzulhelmi MN, Nurul F, Muhamad F, Teo TM, et al. Diversity and composition of beetles (Coleoptera) in three different ages of oil palms in Lekir oil palm plantation, Perak, Malaysia. Serangga. 2018;23(1):58-71.
13. Gintoron CS, Mohammed MA, Sazali SN, Deka EQ, Ong KH, Shamsi IH, et al. Factors affecting pollination and pollinators in oil palm plantations: a review with emphasis on the *Elaeidobius kamerunicus* weevil (Coleoptera: Curculionidae). Insects. 2023;14(5):454. https://doi.org/10.3390/insects14050454
14. Mohamad SA, Ahmad SN, Syarif MNY, Sulaiman MR, Hung KJ, Mohammed MA, et al. Population abundance of oil palm pollinating weevil, *Elaeidobius kamerunicus* Faust and its relation to fruit set formation in mineral and peat soil areas in Peninsular Malaysia. Serangga. 2021;26:107-17.
15. Paterson RRM, Kumar L, Taylor S, Lima N. Future climate effects on suitability for growth of oil palms in Malaysia and Indonesia. Sci Rep. 2015;5:14457. https://doi.org/10.1038/srep14457
16. United States Department of Agriculture. Commodity intelligence report: Malaysia palm oil-beneficial weather helps to increase annual production [Internet]. Washington (DC): Foreign Agricultural Service; 2019
17. Jalloh M, Osekre EA, Adu-Acheampong R, Dumbuya G. Impact of management practices in cocoa farms on soil-dwelling arthropods in the Eastern Region of Ghana. J Exp Biol Agric Sci. 2018;6(2):386-95. https://doi.org/10.18006/2018.6(2).386.395
18. Oettli P, Behera SK, Yamagata T. Climate-based predictability of oil palm tree yield in Malaysia. Sci Rep. 2018;8:1-13. https://doi.org/10.1038/s41598-018-20298-0
19. Stiegler C, Meijide A, Fan Y, Ashween Ali A, June T, Knohl A. El Niño-Southern oscillation event reduces CO_2 uptake of an Indonesian oil palm plantation. Biogeosciences. 2019;16(14):2873-90. https://doi.org/10.5194/bg-16-2873-2019
20. Paterson RRM, Kumar L, Shabani F, Lima N. World climate suitability projections to 2050 and 2100 for growing oil palm. J Agric Sci. 2017;155(5):689-702. https://doi.org/10.1017/S0021859616000605
21. Rafii MY, Isa ZA, Kushairi A, Saleh GB, Latif MA. Variation in yield components and vegetative traits in Malaysian oil palm (*Elaeis guineensis* Jacq.) *dura* × *pisifera* hybrids under various planting densities. Ind Crops Prod. 2013;46:147-57. https://doi.org/10.1016/j.indcrop.2012.12.054
22. Yue J, Yan Z, Bai C, Chen Z, Lin W, Jiao F. Pollination activity of *Elaeidobius kamerunicus* (Coleoptera: Curculionoidea) on oil palm on Hainan Island. Fla Entomol. 2015;98(2):499-505. https://doi.org/10.1653/024.098.0217
23. Fatihah AN, Fahmi MM, Luqman HA, Nadiah SS, Teo TM, Riza HI, et al. Effects of rainfall, number of male inflorescences and spikelets on the population abundance of *Elaeidobius kamerunicus* (Coleoptera: Curculionidae). Sains Malays. 2019;48(1):23-31. https://doi.org/10.17576/jsm-2019-4801-03
24. Rafii MY, Rajanaidu N, Jalani BS, Kushairi A. Performance and heritability estimations on oil palm progenies tested in different environments. J Oil Palm Res. 2002;14(1):15-24.
25. Arolu IW, Rafii MY, Marjuni M, Hanafi MM, Sulaiman Z, Rahim HA, et al. Breeding of high-yielding and dwarf oil palm planting materials using Deli *dura* × Nigerian *pisifera* population. Euphytica. 2017;213:1-15. https://doi.org/10.1007/s10681-017-1943-z
26. Myint KA, Amiruddin MD, Rafii MY, Abd Samad MY, Ramlee SI, Yaakub Z, et al. Genetic diversity and selection criteria of MPOB-Senegal oil palm (*Elaeis guineensis* Jacq.) germplasm by quantitative traits. Ind Crops Prod. 2019;139:111558. https://doi.org/10.1016/j.indcrop.2019.111558

27. Berk KN. Comparing subset regression procedures. Technometrics. 1978;20(1):1-6. https://doi.org/10.1080/00401706.1978.10489609
28. Montgomery DC, Peck EA, Vining GG. Introduction to linear regression analysis. 5th ed. Hoboken (NJ): John Wiley & Sons; 2021. p. 12-388.
29. Haruna AO, Ch'ng HY. Statistical analysis system (SAS) for agricultural research. Kuala Lumpur: University of Malaya Press; 2017. p. 143-210.
30. Kennedy WJ, Bancroft TA. Model building for prediction in regression based upon repeated significance tests. Ann Math Stat. 1971;42(4):1273-84. https://doi.org/10.1214/aoms/1177693240
31. Bendel RB, Afifi AA. Comparison of stopping rules in forward stepwise regression. J Am Stat Assoc. 1977;72(357):46-53. https://doi.org/10.1080/01621459.1977.10479905
32. Suharjito JF, Koeswandy YP, Nurhayati PWD, Asrol M, Marimin. Annotated datasets of oil palm fruit bunch piles for ripeness grading using deep learning. Sci Data. 2023;10(1):72. https://doi.org/10.1038/s41597-023-01958-x
33. Yousefi M, Rafie ASM, Abd Aziz S, Azrad S. Introduction of current pollination techniques and factors affecting pollination effectiveness by *Elaeidobius kamerunicus* in oil palm plantations at regional and global scales: a review. S Afr J Bot. 2020;132:171-9. https://doi.org/10.1016/j.sajb.2020.04.017
34. Rizal M, Tsan FY. Rainfall impact on oil palm production and oil extraction rate at FELDA Triang 2. In: Proceedings of the 4th International Plantation Industry Conference and Exhibition; 2014; Kuching, Sarawak. p. 1-7.
35. Sarkar MSK, Begum RA, Pereira JJ. Impacts of climate change on oil palm production in Malaysia. Environ Sci Pollut Res Int. 2020;27:9760-70. https://doi.org/10.1007/s11356-020-07601-1
36. Wulandari R, Abas A, Abdullah A. Understanding the impact of climate change on oil palm plantations: a systematic literature review. Front Sustain Food Syst. 2025;9:1621217. https://doi.org/10.3389/fsufs.2025.1621217
37. Samsudin AI, Vetaryan S, Ahmad Mokhtar MA, Abdul Rahim MF, Ting NC, Zolkafli SH, et al. Genome-wide association study for compactness traits in oil palm (*Elaeis guineensis* Jacq.). Euphytica. 2025;221(5):1-15. https://doi.org/10.1007/s10681-025-03502-x
38. Lim KH, Goh KJ, Kee KK, Henson IE. Climatic requirements of oil palm. In: Goh KJ, Chiu SB, Paramananthan S, editors. Agronomic principles and practices of oil palm cultivation. Kuala Lumpur: Malaysian Palm Oil Board; 2011. p. 1-46.
39. Isenmila AE. Relations between oil palm yield and cliatic factors under differential irrigation regimes. In: Proceedings of the 2001 PIPOC International Palm Oil Congress, Agriculture Conference; 2001; Kuala Lumpur. Kuala Lumpur: Malaysian Palm Oil Board; 2001. p. 568-77.
40. Swaray S, Musa AJ, Koroma SA, Sesay M, Musa M, Jalloh M. Phenotypic assessment of oil palm diversity through field-level screening for improved yield performance on Njala upland soil. Int J Plant Soil Sci. 2025;37(8):482-96. https://doi.org/10.9734/ijpss/2025/v37i85649
41. Myint KA, Amiruddin MD, Rafii MY, Abd Samad MY, Izan Shairul. Character interrelationships and path analysis for yield components in MPOB-Senegal oil palm germplasm. Sains Malays. 2021;50:699-709. https://doi.org/10.17576/jsm-2021-5003-12
42. International Society of Oil Palm Agronomy. Current status of oil palm fruit set in Malaysia. Kuala Lumpur: ISOPA; 2019
43. Ahmad MM, Yaseen M, Saqib SE. Climate change impacts of drought on the livelihood of dryland smallholders: implications of adaptation challenges. Int J Disaster Risk Reduct. 2022;80:103210. https://doi.org/10.1016/j.ijdrr.2022.103210
44. Ratner B. The correlation coefficient: its values range between +1/−1, or do they? J Target Meas Anal Mark. 2009;17(2):139-42. https://doi.org/10.1057/jt.2009.5
45. Schober P, Boer C, Schwarte LA. Correlation coefficients: appropriate use and interpretation. Anesth Analg. 2018;126(5):1763-8. https://doi.org/10.1213/ANE.0000000000002864
46. Adam H, Collin M, Richaud F, Beulé T, Cros D, Omoré A, et al. Environmental regulation of sex determination in oil palm: current knowledge and insights from other species. Ann Bot. 2011;108(8):1529-37. https://doi.org/10.1093/aob/mcr151

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonepublishing.com/journals/index.php/PST/open_access_policy

Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etcSee https://horizonepublishing.com/journals/index.php/PST/indexing_abstracting

Publisher information: Plant Science Today is published by HORIZON e-Publishing Group with support from Empirion Publishers Private Limited, Thiruvananthapuram, India.