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# Reactions of Oil Palm (*Elaeis guineensis* Jacq) Progenies to Fusarium Wilt Disease Caused by *Fusarium oxysporum* f.sp. Elaeidis under Natural Infection

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## Abstract

The oil palm (*Elaeisguineensis* Jacq) is used worldwide in commercial agriculture for the production of palm oil, palm kernel oil and palm wine. It produces more oil per plant than any other oil-producing crop in the world. Production is constrained by several factors among which pests/diseases are of utmost importance. Vascular wilt (VW) caused by *Fusarium oxysporum* is the most devastating disease infecting this crop. Its soil-borne ecology has made the use of fungicides to manage this disease too expensive and inpragmatic. There is need for concerted research in the breeding and selection of wilt-tolerant progenies as an essential step in the management of Fusarium wilt disease. The study aims to assess the incidence and severity of vascular wilt among tested oil palm progenies, to evaluate the reduction in yield caused by the disease in the susceptible progenies and to identify the wilt-tolerant, high-yielding progenies. The study was carried out at Pamol Plantations Limited (PPL) in Ndian Estate (Ndian Division), in the Southwest Region of Cameroon. Three field trials were evaluated for tolerance/susceptibility to Fusarium wilt. Each trial consisted of 15 oil palm progenies replicated 4 times. Each progeny had 25 oil palm stands in each replicate. Hence, a total of 1500 oil palm stands were assessed. The experimental design was a randomized complete block (RCB) with trial codes: Trial 2001/1, planted in 2001; Trial 2001/2, planted in 2002; Trial 2001/3, planted in 2003. Each trail had an area of 12 ha, with a plant density of 143 palms·ha$^{-1}$. Wilt incidence, severity, index, and yield were

evaluated on 45 progenies from the 3 trails after identifying *Fusarium oxysporum* from oil palm plant part. Data was subjected to analysis of variance, Fischer's least significant difference test (LSD) for mean separation. Identification of Fusarium was based on descriptive analysis. Incidence of VW in the 3 trials ranged from 1% - 39%. Also, 45% of infected plants were from progeny 676 while 1% was from progenies 689, 693, 694 and 710. Disease severity was from 0.9 in progeny 686 to 4.55 in 676. Wilt index ranged from 131 for progeny 694 and 710 to 495 for progenies 705. Out of the 45 progenies evaluated, 27 were tolerant ($1 < 100$) and 18 susceptible ($1 \geq 100$). Within the tolerant progenies, 4 were significant ($1 < 20$) while 5 out of 18 were significantly susceptible ($1 \geq 185$). Mean yield reduction of the susceptible progenies was 34.8% while in the tolerant progenies, it increased by 9.5% when compared to their controls. Progenies 702, 703 and 709 are recommended for planting based on the level of tolerance to Fusarium wilt disease and yield.

## Keywords

Progenies, Tolerant, Susceptible, Vascular Wilt, *Fusarium oxysporum*, Oil Palm

## 1. Introduction

The genus *Elaeis* has two species of economic importance in the Arecaceae: The African oil palm (*Elaeis guineensis* Jacq.) which is native to West Africa and the American oil palm (*Elaeis oleifera*), native to Tropical Central America and South America [1]. This plant is used in commercial agriculture for the production of palm oil, kernel oil and palm wine [2]. The oil palm is very profitable because it produces more oil per land area than any other oil-producing crop, such as soybean [3]. In addition, since the oil palm has an average production life span of about 25 years, productivity is combined with a perennial oil source, unlike annual oil seed crops such as soya, making this plant the highest in total world's production of vegetable oils [4].

Approximately 77% of palm oil produced worldwide is used for human consumption making it an indispensable source of edible oil [5] and the remaining 23% is used in manufacturing biodiesel, drugs, cosmetics, polish, and soap detergent [6]. Palm oil is nutritious and useful for bone, joint and skin health, source of medium-chain fatty acids and healthy unsaturated fats. It is a well-balanced fat, with 39% oleic acid (omega-9) and 10% linoleic acid (omega-6) which helps to lower blood cholesterol levels in the body. It is the richest vegetable oil source of Tocotrienols—potent forms of Vitamin E that strengthens the immune system and protects skin cells from toxins and UV radiation [7]. From its reddish-orange hue, this oil is also a good source of $\beta$-carotene, a nutrient found in sweet potatoes, carrots, and other orange foods that are useful as a precursor to vitamin A (retinol) in the body. In traditional medicine, palm oil is used as an ingredient for the cure

of ailments such as headaches, pains, rheumatism, cardiovascular diseases and arterial thrombosis [8]. Healthwise, palm oil intake has no impact on body weight changes or Body Mass Index (BMI) [9].

Severe drought (8 - 10 months), infertile soil and disease are the major factors that limit oil palm yields [4]. Vascular wilt, otherwise known as Fusarium wilt, is among the most serious diseases affecting oil palm yield in Africa. The disease is caused by a soil-borne fungus, *Fusarium oxysporum* Schl. f.sp. elaeis [10]. Wardlaw first observed the disease in Zaire in 1964 and thereafter, it has also been recorded in Nigeria, Ivory Coast, Republic of Benin and Cameroon. This disease has not been reported in Malaysia, which is one of the world-leading exporters of palm oil [11]. Colhoun [12] suggested that climatic differences, notably the lack of prolonged dry season in Malaysia, could be a significant factor in disease expression. Palm oil production from South-East Asia, notably Malaysia, has increased steadily over recent years. In contrast, production in much of Africa has fallen due in part to diseases, with VW being considered as the most serious [13]. The significance of the disease in Africa with particular reference to Cameroon cannot be over-emphasized. The disease is fatal in the acute form of field-planted palms causing high economic losses in mature oil palm plantations. In the chronic form, it retards vegetative growth and prevents the production of fruit bunches. It is more severe in replanted estates, where incidence of up to 40% has been recorded in field-planted palms in some Pamol plantations, in Cameroon [14]. The causal organism of the disease is widely distributed in tropical soils, thereby creating practical difficulties to chemical control measures. Systemic fungicides like Benomyl can be used with limited success to treat infected oil palm fields, but such treatment would be too expensive over large areas [15]. Other measures to manage this disease include sanitation, use of resistant cultivars, clean propagation materials and oil palm seeds should be treated with hot water. Also, it is essential to lime the soil and use nitrate nitrogen fertilizer [16]. Oil palm is a cross-pollinated crop with a long generation time, thereby posing a lot of challenges in achieving a sustainable high yield and quality [16]. The complexity of the disease calls for concerted research in the breeding and selection of wilt-tolerant progenies as one essential step in the control of Fusarium wilt [17]. The objectives of the study, therefore, were to assess the incidence and severity of vascular wilt among tested oil palm progenies, to evaluate the reduction in yield caused by the disease in the susceptible progenies and to identify the wilt-tolerant, high yielding progenies.

Oil palm improvement, through the use of high yielding, wilt-tolerant planting material, would increase the oil yield per hectare [18]. The study is also important in that the strict use of wilt-tolerant seeds in areas with a disease history of wilt would go a long way in minimizing losses due to the disease to no more than one percent [19]. In addition, differences in tolerance among the tested progenies with regards to vascular wilt disease would enable conclusions to be drawn as the choice of planting materials for wilt-infested zones. The most tolerant progenies would be reserved for breeding and seed production programmes.

## 2. Methodology

### 2.1. Study Site

The study was carried out at PPL, Ndian Estate (Ndian Division), Southwest Region of Cameroon. Ndian Estate with 8000 hectares of palm is one of the three estates of PPL, and it is composed of three camps: Mana. Bulu and Makepe Camps. It has an average monthly temperature of 26.5˚C and an average monthly rainfall of 12.9 mm [20]. The area is about 6165 $Km^2$, has an equatorial maritime climate and a dominant lowland topography. It lies between Latitudes 4˚17' - 5˚26' and Latitudes 8˚35' - 9˚26' with an altitude of 1,764m above sea level [21]. Rainfall is ranged between 2500 mm - 4000 mm with maximum between July and October, mean annual temperature between 16˚C and 26˚C and soil types include: dark brown alluvial, lateralitic and silty alluvium which are good for plantation agriculture especially the oil palm and cocoa [22] (**Figure 1**). Fusarium wilt occurs in many parts of Cameroon, but the disease is more prevalent in Ndian Division, where incidence of up to 40% has been recorded in some old fields.

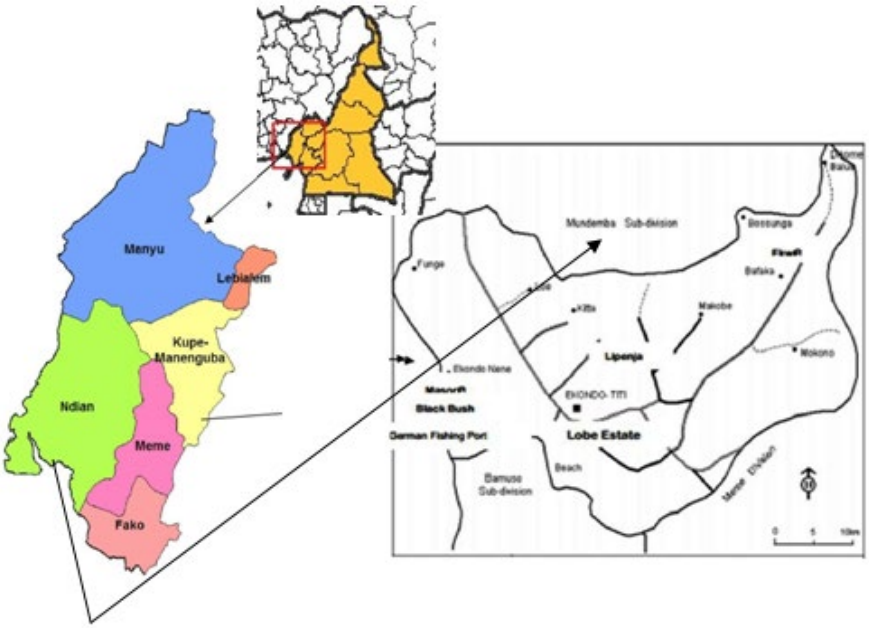



**Figure 1.** Location of the study site in Ndian Division, Southwest region, Cameroon. *Source*: [21].

Three field trials were carried out to determine the tolerance/susceptibility to Fusarium wilt. Each trial consisted of 15 oil palm progenies replicated 4 times. Each progeny had 25 oil palm stands in each replicate. Hence, a total of 1500 oil palm stands were assessed in each trial, that is, 15 progenies × 25 oil palm trees × 4 replicates = 1500 oil palm trees. The experimental design was a randomized complete block (RCB) and the trial codes were: Trial 2001/1, planted in 2001; Trial 2001/2, planted in 2002 and Trial 2001/3, planted in 2003 making a total of 45 progenies (**Table 1**). Each trail had an area of 12 ha, with a plant density of 143

palms·ha$^{-1}$. The basic layout of the palms was 9 m × 9 m triangular.

**Table 1.** List of 45 progenies planted for the three years.

| Progeny Codes | Parents |
|---|---|
| 710 | 12/0516T × 12/12630T |
| 694 | 13/2548D × 12/12640P |
| 683 | 52/1340D × 13/2068D |
| 679 | 13/0837T × 52/1340D |
| 685 | 13/2068D × 12/12440P |
| 693 | 52/1424T × 12/1402D |
| 698 | 13/2959T × 12/0719D |
| 689 | 13/2959T × 52/1239D |
| 685 | 13/2068D × 12/12440P |
| 680 | 13/0837T × 13/2068T |
| 674 | 52/1340D × 13/0837T |
| 684 | 13/2548D × 12/12640T |
| 707 | 52/5334D × 12/10516T |
| 706 | 13/1572T × 12/12539T |
| 685 | 13/2068D × 12/12440P |
| 686 | 52/1340D × 12/12640P |
| 683 | 52/1340D × 12/12640P |
| 709 | 12/12539D × 13/1302T |
| 713 | 13/1302T × 52/11505T |
| 703 | 13/3021D × 52/5334D |
| 699 | 13/2548D × 12/1402D |
| 708 | 13/3021D × 12/10516T |
| 702 | 52/1533D × 12/12539D |
| 675 | 12/1514T × 52/1340D |
| 701 | 12/0719D × 12/12440P |
| 696 | 13/2548D × 12/1402D |
| 672 | 52/1340D × 13/2068D |
| 711 | 12/2630T × 13/3021D |
| 692 | 13/3217T × 52/0424T |
| 700 | 13/3217T × 52/0635T |
| 704 | 13/2065T × 13/3021D |
| 691 | 52/2601T × 12/1239D |
| 695 | 12/1402D × 13/3217T |
| 682 | 52/1514T × 53/0230T |
| 681 | 52/0230T × 13/2068T |
| 690 | 12/3217T × 13/2548D |

**Continued**

| | |
|---|---|
| 694 | 12/0719D × 52/2608T |
| 678 | 12/1514T × 13/0837T |
| 684 | 13/2548D × 12/12649P |
| 697 | 52/0635T × 13/2548D |
| 673 | 13/0837T × 12/1514T |
| 677 | 52/0230T × 52/1340D |
| 676 | 52/0230T × 12/1514T |
| 712 | 12/12539D × 52/11505T |
| 705 | 12/0719D × 52/6117T |

## 2.2. Fusarium Wilt Assessment

### 2.2.1. Incidence of Fusarium Wilt

For each trial, all palm entries in each progeny were inspected for fusarium wilt symptoms. During this operation, the following records were made:

- The number of wilted trees (trees showing chronic or acute symptoms).
- The number of vacant posts (due to trees which have died of the disease).
- The incidence of wilted trees per progeny was calculated as follows:

$$\text{Incidence of wilted trees in each progeny} = \frac{\text{Number of trees showing wilt symptoms}}{\text{Total number of trees in the progeny}} \times 100\% \quad (1)$$

### 2.2.2. Severity of Fusarium Wilt

Symptoms of fusarium wilt were observed in ten randomly selected trees in each progeny. A wilt index of 0 to 5, adopted from Flood *et al.* [23] was used to express severity of disease in each progeny.

0) No symptoms.

1) Slight necrosis/chlorosis on one or two leaves tips—usually oldest leaves.

2) Necrosis/chlorosis over one quarter of leaves of plant and some shortening of the younger leaves.

3) Severe necrosis/chlorosis over one half of the leaves of the plant and some shortening of the younger leaves.

4) Severe necrosis/ chlorosis over three quarters of the leaves of the plant. Extensive leave desiccation and stunting.

5) Dead plant.

Vascular wilt disease severity = Number of plants were counted per severity score on a scale of 1-5.

$\overline{X}$ ISSAP $= \left(\sum_{s=1}^{5}(SXs)\right) \Big/ \left(\sum_{s=1}^{5}(Xs)\right)$ as described in Njock, 1994 and Oben *et al*, 2021). Where:

$\overline{X}$ ISSAP = Mean index of severity considering all plant units;

$S$ = Severity class (1-5);

$Xs$ = Number of plant units scored in severity class (1-5);

$AP$ = Consider all plants units. (2)

### 2.2.3. Fusarium Wilt Disease Index

The performance of each progeny with respect to fusarium was defined by an index (I) whose value is an inverse proportion to the tolerance of the progeny under consideration [19]. Thus, to each progeny corresponds an index (I) obtained by the following formula:

$$\text{Index rating } (\text{I}) \text{ for each progeny} = \frac{\text{Percentage of wilted plants in a progeny}}{\text{Average percentage of wilted plants in all progenie}} \times 100$$

The lower the rating (I), the higher the tolerance of the progeny under consideration. Thus, by the end of the fusarium wilt assessment, progenies were classified in relation to each other in order to increase susceptibility to wilt.

Each breeding parent was attributed to the mean of the indices of the crosses in which it is inscribed a value (Ig). The Ig value indicate that parent's "combining ability", that is the parent's capacity to transmit to its progeny either a certain tolerance if the figure is less than 100, or susceptibility if the Ig value is more than 100. Classification of parent's as regards tolerance or susceptibility of the wilt was based on their Ig value [24].

## 2.3. Vegetative Measurement

For each progeny, the following vegetative measurements were carried out for 10 randomly selected trees as described by Corley [25].

### 2.3.1. Palm Height

A graduated pole was used to measure the height of each palm. Measurements were made from ground level to the base of frond 41 in meter to one decimal place.

### 2.3.2. Leaf Length, Leave Area and Number of Leaflet

The existence of gradient in leaf sizes according to the ages of the leaves means that samples must be taken from leaves of the same rank to enable comparison between different samples. Leave 17 was chosen because it is mature and functionally assessable [15]. In order to determine leaf 17, leaves 1 and 9 were first determined. Leaves 1, 9, and 17 are located on the same spiral. Leaf 1 is the first fully opened leaf surrounding the spear. Leaf 9 is directly below leaf 1, while leaf 17 is directly below leaf 9. Leaf length was measured in meters to one decimal place from the lowest spine to the leaf tip, with the aid of a plastic measuring tape. Relative leaf area was calculated as follows:

$$\text{Leaf area} = \text{length of the longest leaf} \times \text{width of the leaflet} \times \text{number of leaflets} \times \text{frond shape factor}(0.573)$$

### 2.3.3. The Trunk Diameter

They were measured directly with a measuring tape in centimeters to one decimal place. For tall palms, measurements were made at breast height. For stunted

palms, measurements were made at 5 cm from the base of the lower frond.

#### 2.3.4. Number of Leaves (Fronds)

The phyllotaxy of fronds in the crown of an oil palm tree shows that the fronds are spirally arranged around the stem. Each oil palm tree contains eight spirals of fronds [11]. Hence, the number of fronds in each tree was determined as follows:

$$\text{Number of fronds} = \text{Number of fronds in one spiral} \times 8 \quad (4)$$

### 2.4. Harvest and Measurement of Yield

Harvesting of ripe bunches was done with a Malayan knife, attached to a pole of varying length. Bunches which had more than one loose fruits were considered ripe [4]. For each progeny, the bunch weight and number were determined and recorded. Bunches were weighed on a measuring scale, mounted on a tripod stand. Harvesting and recording of fresh fruit bunches were carried out in 10 to 12 days cycle, for 9 months. The harvesting process started in April and ended in December. The percentage decrease in yield of susceptible progenies (R) was compared to the yield of the tolerant check (control) as described by Corley *et al.* [25] as follows:

$$R = \frac{C - W}{C} \times 100\% . \quad (5)$$

$R$ = Relative yield reduction

$C$ = Average yield in the tolerant check

$W$ = Average yield in the susceptible progeny

### 2.5. Microbial Identification

#### Methods

1) Sterilization of laboratory materials and preparation of growth media

Detergents were used to wash glassware for the experiment. Inoculation needles, cork borers and scalpels were dipped into 70% ethanol and flamed to red hot using a Bunsen flame to effect sterilization. Glassware like beakers, pipettes agar plates were sterilized by heating at 120˚C for an hour in hot air oven while the laminar flow Hood was cleaned with cotton wool soaked in 70% ethanol. The UV-light of the lamina flow hood was put on for at least 2 hours and put off before plating of the various samples in semi-solidified agar. Media including Potato dextrose agar, nutrient agar, bacto-agar, carnation leaf agar were suspended individually in one litre conical flask containing distilled water in a water bath and heated for 20 minutes at 50˚C and later autoclaved at 121˚C for 20 minutes to effect sterilization before they were cooled and stored at 4˚C in a refrigerator until when needed.

2) Isolation and identification of Fusarium

3) Source of material for isolation

Equipment used was sterilized and growth media was prepared as described earlier. Leaf tissue from some randomly selected tolerant and susceptible progenies were examined with light microscopeFusarium isolates were identified by

streaking sample portions on Peptone-pentachloronitrobenzene (PPA) a selective medium for isolation of *Fusarium* sp. and the other fungi, sub-cultured in potato dextrose agar (PDA). Single spores were plated and incubated on water agar for a day; in complete medium for seven days and on carnation leaf agar for 2 weeks. Pure fungal cultures raised were identified based on colony morphology and microscopic examination of their spores [26].

All microscopic examination of fungal isolates was done by teasing a small portion of the material with a sterilized needle on a slide using lactophenol and covering with a cover slip before mounting on a microscope. Sub-culturing was done by cutting a 2 $mm^2$ portion of growing mycelium using a sterile needle and placing it centrally on a fresh plate containing PDA. All magnifications were done on X100 and or X400 depending on clarity of the micrographs.

Colony morphology, growth rates and presence of pigments was identified on PDA alongside microconidia (shape, size, number of septa, shape of basal and apical cells, presence of chlamydiospores, conodiogenous cells (monophylides and polyphylides) and spore type. Description of microconidia was done with the use of the mycological dictionary of Kirk *et al.* [27], while Rayners mycological chart [28] and Hawsksworth *et al.* [29] terminologies were used in describing colony colours and nature of their edges, zonation and texture of aerial mycelium.

### 2.6. Data Analysis

Data on disease indices, number of bunches and the average bunch weight, were subjected to a two-way analysis of variance, followed by Fischer's least significant difference test (LSD) for mean separation. A correlation analysis [30] was computed between disease incidence and disease severity of the susceptible progenies. Identification of fusarium was based on descriptive statistics.

## 3. Results

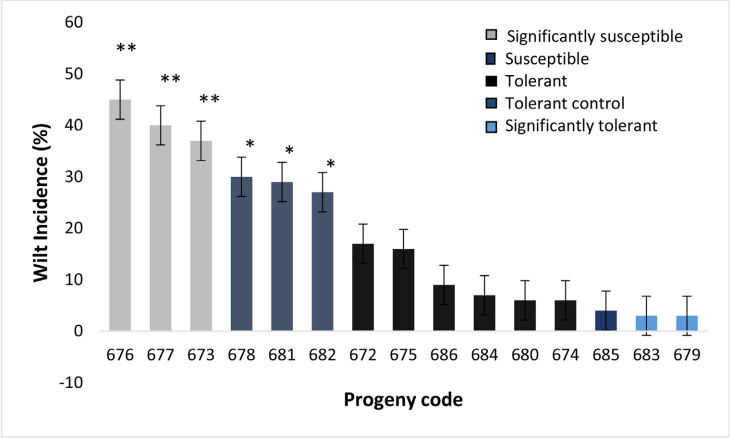
### 3.1. Wilt Incidence

The incidence of wilt in the three trials is given in **Figures 2(a)-(c)** as percentages of affected palms for each progeny. Trees which died as a result of the disease are taken into consideration.

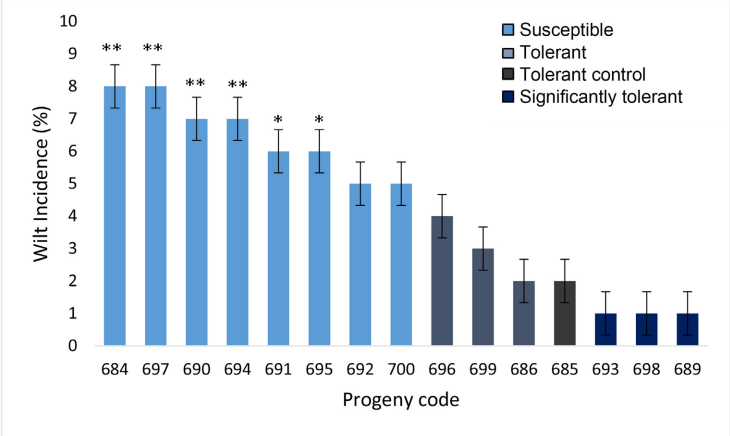
The incidence of vascular wilt ranged from 3% to 45%, 1% to 8% and 1% to 39% in trials 2001/1, 2001/2 and 2001/3, respectively. The highest percentage of infected palms (45%) was recorded in progeny 676 (**Figure 2(a)**). On the other hand, only 1% of the palms of progenies 693, 689, 698, 710 and 694 showed external symptoms. No progeny had zero-rated incidence.

### 3.2. Disease Severity Rating (DSR)

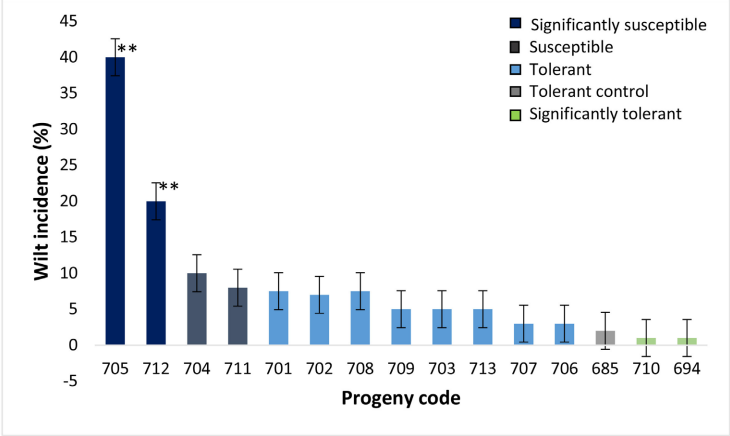
Disease severity ratings (on scale of 1-5) ranged from 0.9 for progeny 686 to 4.55 for progeny 676 (**Table 2**) with highest for progeny 676 (4.5) and the lowest with 0.9 for progeny 686.




(a)




(b)




(c)

**Figure 2.** (a) Incidence of Fusarium wilt in trial 2001/1. *Differs significantly from control at 5% level of probability, $LSD_{0.05}$ = 20; **Differs significantly from control at 1% level of probability, $LSD_{0.01}$ = 27. (b) Incidence of Fusarium wilt in trial 2001/2. *Differs significantly from control at 5% level of probability, $LSD_{0.05}$ = 3.5; **Differs significantly from control at 1% level of probability, $LSD_{0.01}$ = 4.8. (c) Incidence of Fusarium wilt in trial 2001/3. *Differs significantly from control at 5% level of probability, $LSD_{0.05}$ = 17.8; **Differs significantly from control at 1% level of probability, $LSD_{0.01}$ = 24.1.

**Table 2.** Mean values of disease severity rating (on a scale of 1-5) for selected progenies in trial 91/1.

| Progeny Code | Scale* | | | | | Disease severity Rating (DSR) | Disease Incidence (%) |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | | |
| 676 | 0 | 0 | 0 | 10 | 10 | 4.5 | 45 |
| 677 | 0 | 0 | 1 | 16 | 3 | 4.1 | 40 |
| 673 | 4 | 2 | 0 | 8 | 6 | 3.5 | 37 |
| 678 | 6 | 3 | 0 | 10 | 1 | 2.9 | 30 |
| 681 | 9 | 0 | 0 | 6 | 5 | 2.9 | 29 |
| 682 | 0 | 0 | 0 | 2 | 18 | 2.5 | 27 |
| 672 | 12 | 3 | 1 | 3 | 1 | 1.9 | 17 |
| 675 | 12 | 3 | 2 | 2 | 1 | 1.8 | 16 |
| 686 | 19 | 0 | 0 | 0 | 1 | 0.9 | 9 |
| 680 | 9 | 0 | 0 | 10 | 1 | 2.7 | 2.7 |

*The scale (1-5) is interpreted as follows: 1 = slight necrosis/chlorosis on one or two leaf tips, 2 = necrosis over one-quarter of palm leaves, 3 = severe necrosis/chlorosis over one-half of palm leaves and shortening of youngest leaves, 4 = severe necrosis/chlorosis over three-quarter of the plant, extensive leaf desiccation and stunting, 5 = plant death.

The validity of the two disease assessment methods (% infection and DSR), compared by correlation analysis showed significant positive correlation (r = 0.89).

### 3.3. Disease Index (I)

Disease index was used as an estimate wilt infection per progeny. The values of the indices obtained for the different progeny categories are presented in Table 3.

Wilt indices ranged from 13 (progeny 710 and 694) to 495 (progeny 705). Based on the wilt index values obtained, the progenies were classified in relation to each other and in order of increasing susceptibility to wilt. Of the 45 progenies evaluated, 27 appeared tolerant (I < 100), while 18 were susceptible (I >100). Out of the 27 tolerant, 4 were significantly tolerant (I < 20) while 5 out of the 18 susceptible were significantly susceptible (I > 185).

In Table 4, each parent was classified according to its combining ability, that is, its capacity to transmit to its progeny either a certain tolerance (Ig < 100) or a susceptibility which is generally appreciable (I > 100).

Reactions of the progenies to Fusarium wilt ranged in severity from no wilt symptom to death (Table 5) Affected palms showed growth retardation (Plate 1). Wilting of leaf margins, a paler green colour (chlorosis).

Plate 1. Yellowing of leaves (chlorosis) in a susceptile progeny (714) is a characteristic sign of Fusarium Wilt. In some palms, browning of leaves was observed (Plate 1). Browning of leaves caused by leaflet death in susceptible progeny.

**Table 3.** Classification of oil palm progenies in increasing order of susceptibility to wilt.

| Progeny Codes | Parents | Indices | Progeny Category |
|---|---|---|---|
| 710 | 12/0516T × 12/12630T | 13 | Significantly Tolerant |
| 694 | 13/2548D × 12/12640P | 13 | |
| 683 | 52/1340D × 13/2068D | 16 | |
| 679 | 13/0837T × 52/1340D | 16 | |
| 685 | 13/2068D × 12/12440P | 22 | Tolerant |
| 693 | 52/1424T × 12/1402D | 23 | |
| 698 | 13/2959T × 12/0719D | 23 | |
| 689 | 13/2959T × 52/1239D | 23 | |
| 685 | 13/2068D × 12/12440P | 25 | |
| 680 | 13/0837T × 13/2068T | 27 | |
| 674 | 52/1340D × 13/0837T | 27 | |
| 684 | 13/2548D × 12/12640T | 38 | |
| 707 | 52/5334D × 12/10516T | 38 | |
| 706 | 13/1572T × 12/12539T | 38 | |
| 685 | 13/2068D × 12/12440P | 45 | |
| 686 | 52/1340D × 12/12640P | 45 | |
| 686 | 52/1340D × 12/12640P | 49 | |
| 709 | 12/12539D × 13/1302T | 51 | |
| 713 | 13/1302T × 52/11505T | 51 | |
| 703 | 13/3021D × 52/5334D | 51 | |
| 699 | 13/2548D × 12/1402D | 68 | |
| 708 | 13/3021D × 12/10516T | 76 | |
| 702 | 52/1533D × 12/12539D | 76 | |
| 675 | 12/1514T × 52/1340D | 87 | |
| 701 | 12/0719D × 12/12440P | 89 | |
| 696 | 13/2548D × 12/1402D | 91 | |
| 672 | 52/1340D × 13/2068D | 92 | |
| 711 | 12/2630T × 13/3021D | 102 | Susceptible |
| 692 | 13/3217T × 52/0424T | 114 | |
| 700 | 13/3217T × 52/0635T | 114 | |
| 704 | 13/2065T × 13/3021D | 127 | |
| 691 | 52/2601T × 12/1239D | 136 | |
| 695 | 12/1402D × 13/3217T | 136 | |
| 682 | 52/1514T × 53/0230T | 146 | |
| 681 | 52/0230T × 13/2068T | 157 | |
| 690 | 12/3217T × 13/2548D | 159 | |

**Continued**

| | | | |
|---|---|---|---|
| 694 | 12/0719D × 52/2608T | 159 | Susceptible |
| 678 | 12/1514T × 13/0837T | 162 | |
| 684 | 13/2548D × 12/12649P | 181 | |
| 697 | 52/0635T × 13/2548D | 181 | |
| 673 | 13/0837T × 12/1514T | 200 | Significantly Susceptible |
| 677 | 52/0230T × 52/1340D | 217 | |
| 676 | 52/0230T × 12/1514T | 444 | |
| 712 | 12/12539D × 52/11505T | 454 | |
| 705 | 12/0719D × 52/6117T | 495 | |

**Table 4.** Effects of fusarium wilt on aerial parameters of growth on tolerant oil palm progenies.

| Progeny Code | No. of Fronds | Frond Length (m) | Palm Height (m) | Leaf Area ($m^2$) | No. of Leaflets per Frond |
|---|---|---|---|---|---|
| 693 | 30** | 6.20 | 3.65 | 2.51** | 214** |
| 699 | 24** | 5.40 | 5.10 | 10.37 | 348 |
| 688 | 32** | 6.40 | 4.50 | 13.70 | 368 |
| 685 | 30** | 3.95 | 3.15 | 12.60 | 274** |
| 707 | 40 | 5.77 | 4.10 | 11.14 | 360 |
| 706 | 48 | 5.80 | 3.90 | 12.49 | 374 |
| 685 | 48 | 6.00 | 3.50 | 10.94 | 362 |
| 694 | 48 | 5.50 | 5.80 | 10.37 | 370 |
| 710 | 48 | 5.59 | 4.60 | 9.78 | 400 |
| $LSD_{0.05}$ | 11 | 3.10 | 2.60 | 4.10 | 58 |
| $LSD_{0.01}$ | 14 | 3.90 | 3.20 | 4.90 | 78 |
| CV (%) | 25.2 | 12.9 | 19.9 | 30.90 | 17.2 |

*Significantly different from control P = 0.05; **Significantly different from control at P = 0.001.

**Plate 1.** Oil palm plant showing symptoms of fusarium wilt.

**Table 5.** Effects of Fusarium wilt on aerial parameters of growth on susceptible oil palm progenies.

| Progeny Code | No. of Fronds | Frond Length (m) | Palm Height (m) | Leaf Area ($m^2$) | No. of Leaflets per Frond |
|---|---|---|---|---|---|
| 676 | 28** | 4.44* | 2.90* | 1.39* | 310 |
| 677 | 28** | 4.43** | 2.80* | 2.01* | 278** |
| 673 | 48 | 5.7 | 4.7 | 4.08 | 340 |
| 682 | 32 | 4.4 | 2.66** | 4.08 | 290* |
| 681 | 30 | 4.92 | 3.10 | 2.28 | 290* |
| 678 | 32 | 5.29 | 3.35 | 5.31 | 357 |
| 705 | 40 | 5.65 | 3.3 | 7.68 | 320 |
| 712 | 32 | 4.59* | 2.25** | 2.07 | 299 |
| 685 (Control) | 40 | 5.67 | 3.90 | 7.05 | 328 |
| 675 | 38 | 7.12 | 3.16 | 6.39 | 324 |
| 679 | 48 | 4.00* | 4.50 | 5.36 | 312 |
| $LSD_{(0.05)}$ | 10 | 1.02 | 0.9 | 5.2 | 30 |
| $LSD_{(0.01)}$ | 12 | 1.8 | 1.2 | 8.3 | 38 |
| CV (%) | 20.3 | 17.5 | 24.8 | 50.7 | 9.0 |

The effect of disease on cell elongation (size) was more severe in diseased palms than in the tolerant progenies. In diseased palms, epidermal cell length and width were reduced by 12.7% and 13% respectively from the control.

The mean palm height and frond length of the tolerant progenies (Table 6) were not significantly different from the control palms.

**Table 6.** Effect of Fusarium wilt on fruit yield of susceptible and tolerant oil palm progenies (trial 2001/1).

| Progeny Code | Progeny Class | Mean Bunch No. | Mean Bunch Weight (kg FFB/progeny) | % Yield Deviation from Control |
|---|---|---|---|---|
| 683 | Significant Tolerant | 121 | 1681.5 | +12.9 |
| 679 | | 100 | 1596.9 | +9.2 |
| 685 | Tolerant Control | 118 | 1462.8 | 0 |
| 680 | Tolerant | 95 | 1571.1 | +7.4 |
| 674 | | 101 | 1699.5 | +16.2 |
| 684 | | 113 | 1346.4 | −7.9 |
| 686 | | 154** | 1748.9 | +19.6 |
| 675 | | 134 | 1803.7 | +23.3 |
| 672 | | 105 | 1366.8 | −6.6 |
| 682 | Susceptible | 69** | 619.4** | −57.5 |
| 681 | | 131 | 1233.3 | −15.7 |
| 678 | | 60** | 835.6** | −42.9 |

**Continued**

| | | | | |
|---|---|---|---|---|
| 673 | Significantly Susceptible | 85* | 1272.5** | −13.0 |
| 677 | | 117 | 1119.6* | −23.5 |
| 676 | | 73** | 638.2** | −56.4 |
| $LSD_{0.05}$ | | 27 | 342.3 | |
| $LSD_{0.01}$ | | 38 | | |
| CV (%) | | 6.2 | | |

*Significantly different from control P = 0.05 - 57.5; **Significantly different from control at P = 0.001.

### 3.4. Effect of Fusarium Wilt on Fruit Yield

Fruit yield, expressed as a total weight of fresh fruit bunches (FFB) further discriminated between the relative impacts of wilt infection on the susceptible and tolerant progenies. In trial 2001/1, fruit yield was generally lower on the wilt-susceptible progenies compared to the tolerant ones (Table 7). The mean yield reduction in susceptible progenies was 34.8% while in tolerant progenies, fruit yield was increased by 9.3%, when compared to tolerant control (685). The fruit yield of six tolerant progenies (683, 679, 680, 674, 686 and 675) in trial 2001/1 was higher than that of the tolerant control (Table 7).

Table 7. Impact of Fusarium wilt on fruit yield of susceptible and tolerant oil palm progenies (trial 91/2).

| Progeny Code | Progeny Class | Mean Bunch No. | Mean Bunch Weight (kgFFB/progeny) | % Yield Deviation from Control |
|---|---|---|---|---|
| 694 | Significantly tolerant | 119 | 1505.9 | +8.3 |
| 685 | Control | 120 | 1381.3 | 0 |
| 693 | Tolerant | 134 | 1331.5 | −3.6 |
| 698 | | 113 | 1342.5 | −2.8 |
| 689 | | 73** | 1041.8 | −24.6 |
| 686 | | 152** | 1216.3 | −11.9 |
| 699 | | 107 | 1401.6 | +1.5 |
| 696 | | 134 | 1400.5 | +1.4 |
| 692 | Susceptible | 98 | 1203.3 | −12.9 |
| 700 | | 75** | 983.8* | −28.8 |
| 691 | | 97 | 1240.8 | −10.2 |
| 695 | | 120 | 1381.3 | 0 |
| 690 | | 73** | 1058.9 | −23.3 |
| 684 | | 114 | 1570.1 | +12.0 |
| 697 | | 110 | 1493.7 | +7.5 |
| $LSD_{0.05}$ | | 28 | 348.9 | |
| $LSD_{0.01}$ | | 39 | 484.3 | |
| CV (%) | | 21.2 | 13.5 | |

*Significantly different from control P = 0.05 - 57.5; **Significantly different from control at P = 0.001.

In trial 2001/2, the average yield reductions in the tolerant and susceptible progenies were 31.7% and 55.7%, respectively, when compared to the tolerant control (685). The fruit yield (weight of fresh fruit bunches) of three tolerant progenies (696, 699, 694) and 2 susceptible progenies (684 and 697) was higher than that of the tolerant control (Table 8).

Table 8. Impact of Fusarium wilt on fruit yield of susceptible and tolerant oil palm progenies (trial 2001/3).

| Progeny code | Progeny Class | Mean Bunch No. | Mean Bunch Weight | % Yield Deviation from Control |
|---|---|---|---|---|
| 710 | Significantly tolerant | 92 | 1200.5 | −1.6 |
| 685 | Control | 106 | 1219.5 | 0 |
| 707 | Tolerant | 85 | 1373.3 | +12.6 |
| 706 | | 134 | 1555.6 | +27.6 |
| 709 | | 168** | 1640.6* | +34.5 |
| 713 | | 90 | 1270.8 | +4.2 |
| 703 | | 88 | 1709.5* | +40.2 |
| 708 | | 87 | 1553.2 | +27.4 |
| 702 | | 137 | 1720.6* | +41.1 |
| 701 | | 104 | 1501 | +23.1 |
| 711 | Susceptible | 178** | 856.5 | −29.8 |
| 704 | | 92 | 1393.8 | +24.8 |
| 694 | | 143** | 1522.5 | +24.8 |
| 712 | Significantly susceptible | 159** | 1603.1 | +31.5 |
| 705 | | 145* | 1410.2 | +15.6 |
| $LSD_{0.05}$ | | 34 | 401.9 | |
| $LSD_{0.01}$ | | 48 | 561.7 | |
| CV (%) | | 27.2 | 15.9 | |

*Significantly different from control P = 0.05 - 57.5; **Significantly different from control at P = 0.001.

In trial 2001/3 the average yield increase in tolerant and susceptible progenies was 23.2% and 56.4%, respectively, when compared to the tolerant control (685). A total of 8 tolerant, high-yielding progenies (709, 703, 702, 707, 706, 713, 708 and 701) and 4 susceptible, high-yielding progenies (704, 694, 712 and 705) were identified (Table 8).

Results from the variance analysis showed that the fruit yield (average weight of fresh fruit bunches) of three tolerant progenies (709, 703 and 702) was significantly higher than that of the tolerant control (Table 8). These tolerant, high-yielding progenies; 709, 703 and 702 were derived from the cross: 12/12539D.

### 3.5. Isolation and Identification of Fusarium

From the colony characteristics on Potato dextrose agar, Fusarium isolate exhibited fast growth, producing abundant uniform mycelia and pale brown pigment. On CLA, it had abundant macroconidia that were medium in length, falcate, thin with characteristic 3 septa. The apical cell was hook shaped. Chlamydospores were abundant on the hyphae and microconidia were non-septate, oval in shape and formed on mono phialides (Plate 2).

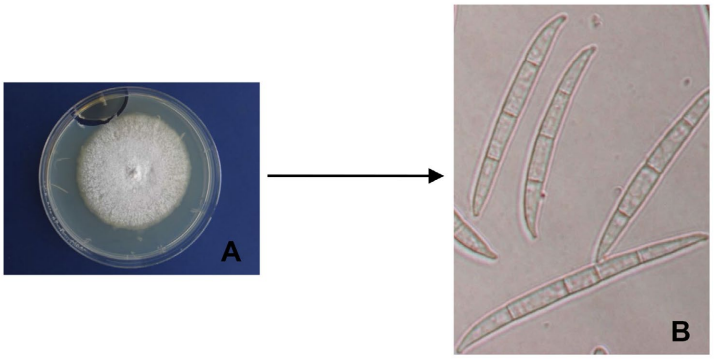



**Plate 2.** Diagnostic features of *Fusarium oxysporium*. Microconidia with mainly 3 septa and foot shaped basal cell.

## 4. Discussions, Conclusions and Recommendations

The performance of a progeny with regard to wilt was defined in relation to the mean percentage of wilt-infected plants in the progeny under consideration. Thus, progenies with indices less than 100 were referred to as tolerant progenies, and those with indices greater than 100 as "susceptible progenies". The most tolerant or susceptible progenies were those with indices furthest from 100 on either side. In the present study, the progenies were, therefore, classified in relation to each other in increasing susceptibility to wilt (Table 2). This classification enables those progenies (710, 694, 683 and 679) to possess better wilt tolerance than the tolerant control (685) to be identified. On the basis of these results, the tolerant crosses should be made again, and their progenies be re-tested by inoculation in the pre-nursery. If the results agree, material should be planted in zones ravaged by wilt.

The fact that there was no progeny with 0% wilt incidence is of much concern. This lack of immunity indicates that resistance of oil palm to *F. oxysporum* f. sp. elaeidis is polygenic, consistent with the findings of De Franqueville, (1991). Two contrasting theories on the inheritance of resistance of *F.oxysporum* f. sp. elaeidis have been proposed. Meunier *et al.* [31] suggested that resistance was inherited through the action of many genes (polygenic) inherited in an additive manner, while De Franqueville [18] proposed that resistance was controlled by the action of just 2 genes (oligonenic). The latter group conducted their experiments at Binga, and therefore their result may reflect the ability of Binga isolates of *F. oxysporum* E sp, elaeidis to distinguish between two separate resistance mechanisms.

Plant pathogens produce various kinds of toxic compounds in plant tissues.

These compounds cause a series of morphological and biochemical changes in plant tissues and contribute to pathogenicity or virulence of the producers [32]. Fusaric acid is a common metabolite of several species of Fusarium which, in many cases, invades the vascular system of host plants. The host plant becomes unable to transport sufficient volume of water to meet up with its transpiration demand, and it therefore wilts.

The failure of some palms (in susceptible progenies) to exhibit symptoms was assumed to reflect the "threshold" nature of disease resistance, rather than the segregation of resistance genes within a cross. The "threshold" theory of disease resistance implies that the pathogen concentration must exceed a certain minimum before infection can occur [33] The "threshold" theory of disease resistance was further supported by the failure of clonal lines (in which there would be no segregation of resistance genes) to exhibit immunity [18].

All the cultivated oil palm progenies were infected with *Fusarium oxysporum* but at different magnitude. Four categories of infection were identified and include; the significantly tolerant, susceptible and significantly susceptible. The significantly tolerant progenies showed the least disease symptoms, disease incidence and severity. Meanwhile, the significantly susceptible progenies showed high levels of symptoms with high incidence and severity of disease.

Detection of a range of disease-tolerant planting materials makes it possible to replace old plantings and establish new oil palm fields that will be high-yielding and disease-resistant.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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