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Research article

Potential coconut (*Cocos nucifera* L.) genotypes for farmers: Evaluation of agronomic traits in a lethal yellowing disease endemic zone in Ghana

Christian Kofi Anthonio, Linda Arhin, Daniel Ansah Fianko, Frederick Leo Sossah, Emmanuel Andoh-Mensah, Ndede Egya Yankey *

Council for Scientific and Industrial Research (CSIR)-Oil Palm Research Institute, Coconut Research Programme, P. O. Box 245, Sekondi, Ghana

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ABSTRACT

A four-year study was conducted to evaluate selected vegetative and reproductive characteristics in four coconut genotypes namely: Niu Leka Dwarf (NLD), New Guinea Brown Dwarf (NGBD), Malayan Green Dwarf (MGD), Indonesian Brown Dwarf (IBD), and a hybrid between Sri Lankan Green Dwarf and Vanuatu Tall (SGDVTT), which was used as a control. The study was located at Anwea in the Western Region of Ghana, an endemic zone to the lethal yellowing disease. This experiment was laid out in a randomized complete block design (RCBD) in three replications. Results showed a significant higher growth for NGBD, IBD, and NLD in stem girth, leaf length, petiole length, and number of leaflets. NGBD, IBD, and SGDVTT also recorded significantly higher reproductive characteristics. Time taken for first flowering was noticed in IBD (41.30 months). NGBD recorded the highest number of female flowers (27.80), number of spikelets with female flowers (17.20), and total number of spadix (12.50) seasonally. Significant and positive correlations were observed between the number of leaves emitted, and the number of female flowers produced in the coconut genotypes except for MGD. The highest correlation between these vegetative and reproductive characteristics was expressed in IBD while the least was observed in the MGD genotype. MGD also recorded the least number of spikelets with female flowers, suggesting that this genotype is not likely to produce high number of fruits and should not be included in future breeding programs. Low and less robust characteristics were expressed in both SGDVTT, and MGD in the growing period, which could be ascribed to the rather low number of leaflets observed in these genotypes. Conclusions from this study suggest that NGBD, IBD, and NLD are potential genotypes to be integrated into further breeding programs across coconut-growing regions in Ghana.

1. Introduction

Coconut (*Cocos nucifera* L.) is a plantation crop that is widely grown in tropical regions, yielding various agricultural products that play a crucial role in export economies [1]. It serves as a key supplier of raw materials for the production of coconut oil, fresh coconut water, milk, coir, and husk [2,3], supporting agro-based industries. Moreover, the coconut palm is also appreciated for its cultural,

* Corresponding author.
E-mail address: ndedeyankey@yahoo.com (N.E. Yankey).

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food, and social significance in some of the poorest regions globally [4]. Coconut is a crucial source of income for small-holder farmers in the coastal belt, rural, and peri-urban communities [5,6].

In Ghana, coconut farmers have primarily relied on the West African Tall (WAT) variety for coconut cultivation over the past decades. However, the WAT variety is susceptible to the lethal yellowing disease, also known in Ghana as the Cape St. Paul Wilt Disease (CSPWD), which is associated with phytoplasma and transmitted by insect vectors. As a result, the coconut industry has experienced significant losses, with more than 20,000 ha of coconut plantations destroyed [7–11]. The decline in production, coupled with other constraints such as poor planting materials, inappropriate agronomic practices, and poor soil conditions, have resulted in only a marginal increase in yield [12,13]. The significant economic losses caused by this devastating disease have deprived farmers of their livelihoods. As a result, enthusiasm for coconut cultivation dwindled in the CSPWD-affected zones, with some farmers turning to other crops and others unable to expand their farms. This has had a lasting negative impact on the coconut industry [14].

However, the hybrid coconut, Sri Lankan Green Dwarf x Vanuatu Tall (SGDVTT), which was developed through years of research [15], has rekindled interest in coconut farming due to its tolerance to the CSPWD in Ghana. Meanwhile, with the dependence on only this coconut hybrid, there is a fear of breakdown in resistance, and thus, more genotypes must be assessed and released into breeding programs across all coconut-growing regions in the country. To this end, four CSPWD-tolerant genotypes (NLD, NGBD, MGD, and IBD) have been identified and could be integrated into breeding programs to provide farmers with alternative planting materials [14]. Additionally, demand for varieties with short vegetative growth periods, early fruiting, and flowering is high. Therefore, screening trials can identify disease-free varieties that could be incorporated into breeding programs to meet farmers' demands.

These challenges in addition to the fact that most coconut farmers have limited access to high-quality planting materials have necessitated the identification of potentially valuable genetic stocks and development of unique trait specific genotypes to give coconut farmers more options. The selected genotypes with their unique traits will further be utilized in crop improvement programs so that the coconut becomes a more profitable crop. One critical and fundamental way to identify these traits is through the exploration of selected agronomic characteristics of the selected palms. Following the paucity of information on vegetative and reproductive characteristics of the selected dwarf genotypes, we hypothesized in the current study that there are correlations between these indicators. However, these correlations may differ among different coconut genotypes due to variations. The present study addressed the following objectives: 1) to evaluate selected agronomic characteristics of four dwarf coconut genotypes identified in a Ghanaian breeding program for commercial production, and 2) analyze the correlations between selected vegetative and reproductive characteristics among these coconut genotypes. The aim is make these genotypes available in all coconut growing areas, which are prone to the lethal yellowing disease. These selected genotypes, through hybridization programs will augment the over exploited hybrid (SGD x VTT) coconut palm in the country.

2. Materials and methods

2.1. Study site

The study was conducted in Anwea (2°05′ W and 2° 35′ W, 4°40' N and 5°20 N) in the Ellembelle district of the Western Region in Ghana from 2017 to 2021. This research field is owned by the Coconut Research Programme. The site is situated in an area where there is high incidence of the lethal yellowing disease, known in Ghana as the Cape St. Paul Wilt Disease (CSPWD). Climatic conditions in the area are highly favorable for coconut cultivation. The site receives an average annual rainfall of 1700 mm, with major rainfall occurring from April to June and minor rainfall from September to October. The dry season usually lasts from mid-November to mid-March, and the annual mean temperature ranges from 25 to 29^{O}C. Soil at the site is sandy loam with a depth greater than 150 cm, and its classification can be found in Table 1.

Table 1
Initial soil physicochemical properties from the Anwea experimental site in 2017.

Soil parameter	Sampling depth (cm)	
	0–20	20–40
pH (1:2.5H_2O)	4.92	5.04
SOM (mg kg^{-1})	0.34	0.21
AN (mg kg^{-1})	0.18	0.16
AP (mg kg^{-1})	4.65	3.67
AK (mg kg^{-1})	0.68	0.65
ACa (mg kg^{-1})	2.89	2.73
Soil classification	Ferric Acrisol	
Sand (%)	68.00	67.00
Silt (%)	20.00	22.30
Clay (%)	12.00	10.70

*SOM: soil organic matter, AN: available Nitrogen, AP: available phosphorus, AK: available potassium, ACa: available calcium.

2.2. Planting materials

The study focused on investigating four dwarf coconut genotypes, namely Niu Leka Dwarf (NLD), New Guinea Brown Dwarf (NGBD), Malayan Green Dwarf (MGD), and Indonesian Brown Dwarf (IBD) (Fig. 1) selected from the institute's conservation field. The seedlings of these dwarf coconut genotypes were originally imported from the International Coconut Gene bank for Africa and the Indian Ocean based in Ivory Coast. Additionally, a hybrid called Sri Lanka Green Dwarf x Vanuatu Tall (SGDVTT) was used as a control in the study. All seedlings were planted at six (6) months old when they attained at least six-leaf stage.

2.3. Experimental design

The experiment was designed using a Randomized Complete Block Design (RCBD) with three replications. The dwarf genotypes were planted in equilateral triangular spacing of 7.5 × 7.5 × 7.5 m, with each plot containing 24 palms. Similarly, the hybrid was planted at 8.5 × 8.5 × 8.5 m spacing, with 24 palms in each plot. Standard management practices were followed to maintain the site, and manual weed control was performed as needed. All experimental plots received fertilizer applications of nitrogen, phosphorus, potassium, and magnesium (N–P_2O_5–K_2O–MgO) at a rate of 258-184-480-124 kg ha^{-1} every 6 months. Pests were monitored regularly, and appropriate measures taken to protect the palms.

2.4. Data collection

2.4.1. Soil sampling and analysis

Soil samples were taken using soil auger from two depths, 0–20 and 20–40 cm, then air-dried for two weeks and sieved through a 2 mm sieve mesh. Physical and chemical analyses were conducted on the soil. The soil's organic carbon content was determined using the modified [16] procedure by Ref. [17]. Soil pH was measured in a 1:2.5 [18] with a glass electrode pH meter (Digital Mettler Toledo meters). Total nitrogen was determined using the Kjeldahl digestion and distillation procedure as described by Ref. [19]. Available phosphorus was determined using the Bray 1 extraction method [20] described by Ref. [21]. The soil's exchangeable bases (calcium, magnesium, and potassium) were determined using a 1.0N ammonium acetate (NH_4OAc) extract by Ref. [22]. Potassium in the percolate were determined by flame photometry, and calcium, and magnesium were determined by atomic absorption spectrometer. Soil texture was determined using the hydrometer method [23]. Table 1 presents soil properties from the experimental site.

2.4.2. Vegetative growth characteristics

Data were collected on thirty (30) coconut palms of each genotype for measuring vegetative characteristics, which included stem girth, leaf production, petiole length, leaf length, and number of leaflets. Collection was done in accordance with the methodology described by Ref. [24], and data were collected at 6 monthly intervals for four years after the plants were field-planted. Leaf production was calculated by counting the number of leaves produced every 6 months, and the annual rate was determined by recording two consecutive counts. Stem girth was measured by placing a measuring tape around the base of the stem just beneath the oldest living frond. Petiole length was measured from the attachment point to the base of the first leaflet insertion. Total leaf length was measured from the stem attachment of the petiole to the tip of the topmost leaflet. The number of leaflets was determined by counting the leaflets from one side of the leaf frond, using the side bearing the leaflet at its lowest insertion in the petiole as the reference side.

Fig. 1. Four years old coconut genotypes from the Anwea experimental site in 2021.

2.4.3. Reproductive characteristics

The first yield indicator evaluated was the time taken by palms to produce their first inflorescence (spadix). Monthly observation for flowering was carried out from the second year after field planting as described by Ref. [25]. The number of spikelets per inflorescence, spikelets with female flowers and number of female flowers for every spathe opening were determined and recorded. Total number of inflorescences that emerged from the palms in a year was counted monthly and recorded.

2.4.4. Assessment of cape saint Paul's wilt disease (CSPWD) incidence among coconut genotypes

All coconut genotypes were sampled and tested for the incidence of lethal yellowing disease every six month starting from 2018 to 2021, following standard protocols comprehensively outlined by Ref. [6]. The plantation was observed for CSPWD symptoms at each sampling period. One palm of each genotype was randomly selected for PCR detection of the phytoplasma associated with CSPWD in Ghana. Leaf rather than trunk boring was used for DNA extraction to avoid severe injuries to the young palms. For all polymerase chain reaction (PCR), 50 ng of DNA template was added to a 25-μL PCR reaction (MangoMix, Bioline-UK). A forward and reverse primer were each used in each reaction at a final concentration of 0.2 μM. A nested PCR assay targeting a section of the 16SrRNA gene was used to detect the CSPWD phytoplasma. A first round PCR was carried out using phytoplasma universal primers P1 [26] and P7 [27]. One microlitre of 40-fold diluted P1/P7 PCR products was used in nested PCR. Primers used in the nested PCR were G813F [28] and GAwkaSR [29]. PCRs were carried out in a programmable Techne Prime thermal cycler (UK). For the P1/P7 assay the following

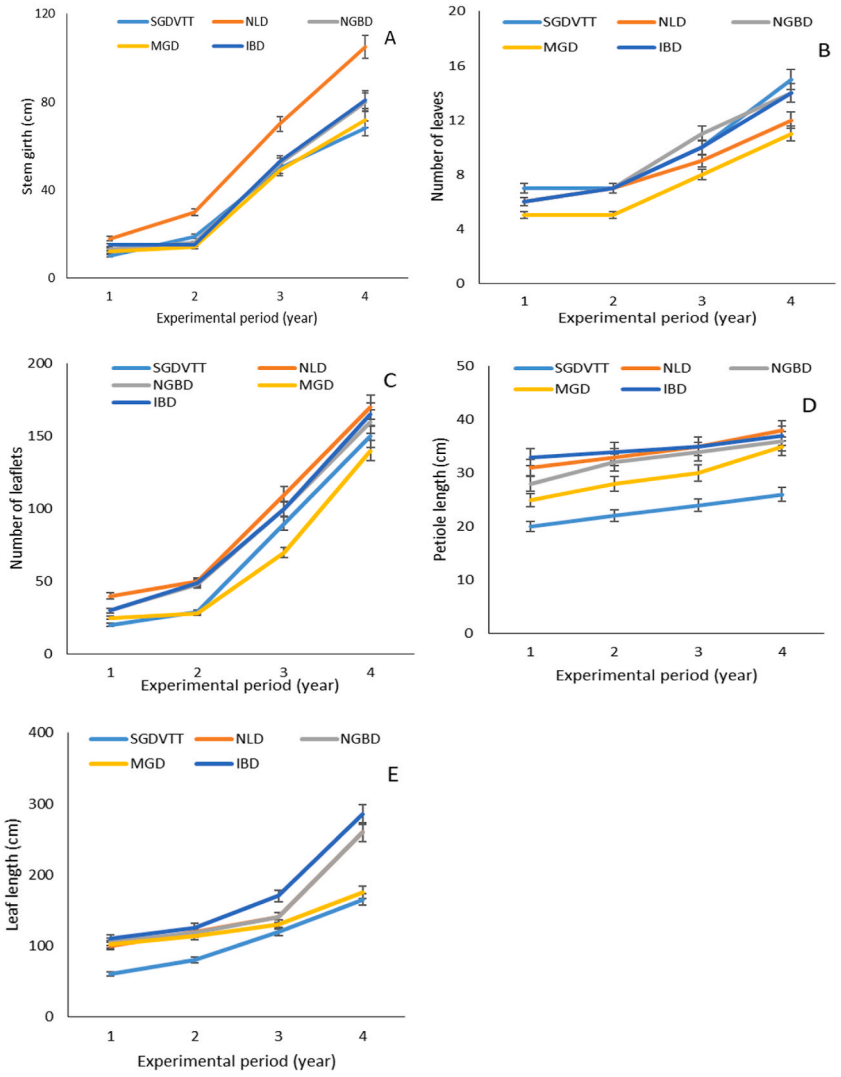

Fig. 2. Vegetative indices: Stem girth (A), Number of leaves (B), Number of leaflets (C), Petiole length (D), and Leaf length (E) among coconut genotypes at $P \leq 0.05$ according to Duncan's multiple range test from Anwea between 2017 and 2021. Bars show standard deviation. SGDVTT = Sri Lanka Green Dwarf x Vanuatu Tall, NLD = Niu Leka Dwarf, NGBD = New Guinea Brown Dwarf, MGD = Malayan Green Dwarf, IBD = Indonesian Brown Dwarf.

conditions were applied: initial denaturation of 94°C for 3 min, followed by 35 cycles of 94°C for 40 s, 56°C for 40 s, and 72°C for 1 min 40 s and a final extension of 72 °C for 10 min. The same conditions were applied for the G813f/GAKSR assay except for the annealing temperature which was 53°C. Five microlitres of the PCR products were separated on 1 % agarose gels in 1X TBE buffer at 100V and visualized in a UV *trans*-illuminator (Vilber Lourmat, France).

2.5. Statistical analysis

Two-way analysis of variance (ANOVA) test was performed in R environment using R statistical software package (version 4.1.0) [30] after data normality check. Means with significant differences were separated with the Duncan's multiple range test, as well as Post Hoc Tests at 5 % probability level. Spearman's rank correlations were used to test relationships among vegetative and yield indicator data set. Figures and tables were produced using Microsoft Excel, 2016 (Microsoft, Redmond, WA, USA).

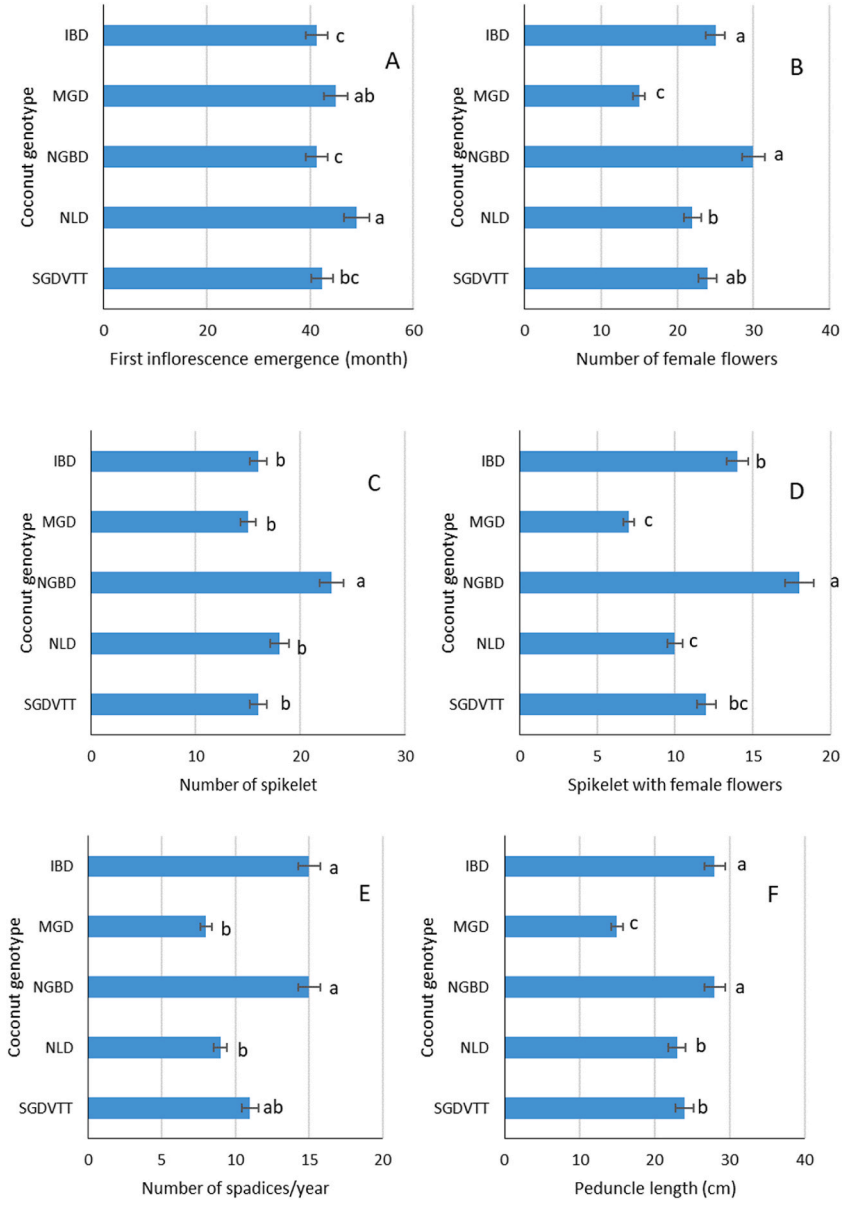

Fig. 3. Reproductive indices: First inflorescence emergence (A), Number of female flowers (B), Number of spikelet (C), Spikelet with female flowers (D), Number of spadices/year (E), and Peduncle length (F) among coconut genotypes at $P \leq 0.05$ according to Duncan's multiple range test from Anwea between 2017 and 2021. Bars show standard deviation. SGDVTT = Sri Lanka Green Dwarf x Vanuatu Tall, NLD = Niu Leka Dwarf, NGBD = New Guinea Brown Dwarf, MGD = Malayan Green Dwarf, IBD = Indonesian Brown Dwarf.

3. Results

3.1. Cape saint Paul's wilt disease (CSPWD) incidence among coconut genotypes

None of the palms was observed to be affected by CSPWD during the period of the study. PCR diagnosis of samples taken from the genotypes at each sampling period did not show the presence of the phytoplasma associated with CSPWD in the palms.

3.2. Vegetative characteristics

Fig. 2A shows the mean stem girth of each coconut genotype for each experimental year. Throughout the study period, the NLD genotype consistently had the largest stem girth, with a measurement of 107.97 cm recorded in the fourth year. This was significantly higher ($P \leq 0.05$) than the other genotypes. On the other hand, MGD had the smallest stem girth of all the genotypes, measuring 72.54 cm in the fourth year (Fig. 2A).

Average number of leaves produced within the first two years was not significantly different among the coconut genotypes with the exception of MGD, which consistently produced the lowest. However, significant differences were observed from third to the fourth year. SGDVTT (13.3), NGBD (12.4), and IBD (12.2) produced significantly ($P \leq 0.05$) higher number of leaves on a yearly basis

Table 2
Correlation coefficient for vegetative and reproductive indicators of coconut varieties.

Indices/Correlation								
SGDVTT	SG	NL	PL	LL	FSE	NSWFF	NFF	SP
SG	1	0.61*	0.16	0.74**	0.65**	0.60*	0.72**	0.75**
NL		1	0.18	0.65**	0.47	0.70**	0.77**	0.57*
PL			1	0.25	0.17	0.07	0.13	0.18
LL				1	0.3	0.84**	0.84**	0.82*
FSE					1	0.33	0.53*	0.78**
NSWFF						1	0.67*	0.72*
NFF							1	0.82**
SP								1
NLD								
SG	1	0.62*	0.23	0.80**	0.62**	0.58*	0.78**	0.74**
NL		1	−0.08	0.62*	0.63*	0.54*	0.64*	0.60*
PL			1	0.21	0.2	0.27	0.28	0.14
LL				1	0.56*	0.61*	0.61*	0.81**
FSE					1	0.38	0.54*	0.48*
NSWFF						1	0.62**	0.38
NFF							1	0.89**
SP								1
NGBD								
SG	1	0.71*	0.45	0.82**	0.72**	0.86**	0.92**	0.83**
NL		1	0.54*	0.68**	0.74**	0.69**	0.78**	0.86**
PL			1	0.53*	0.38	0.23	0.3	0.17
LL				1	0.74**	0.76**	0.81**	0.82**
FSE					1	0.55*	0.55*	0.70**
NSWFF						1	0.77**	0.93**
NFF							1	0.82**
SP								1
MGD								
SG	1	0.35	−0.12	0.76**	0.45	0.43	0.47	0.62*
NL		1	0.44	0.43	0.59*	0.50*	0.55*	0.56*
PL			1	−0.13	0.11	−0.01	0.05	0.02
LL				1	0.50*	0.55*	0.50*	0.75**
FSE					1	0.43	0.39	0.54*
NSWFF						1	0.56*	0.58*
NFF							1	0.87**
SP								1
IBD								
SG	1	0.78**	0.31	0.69*	0.61*	0.61*	0.66**	0.91**
NL		1	0.11	0.62*	0.70**	0.80**	0.87**	0.87**
PL			1	0.23	0.31	0.01	0.16	0.04
LL				1	0.85**	0.85**	0.95**	0.83**
FSE					1	0.75**	0.65**	0.73**
NSWFF						1	0.85**	0.89**
NFF							1	0.88**
SP								1

*Significant at 5 percent level **Significant at 1 percent level.
SG- Stem girth, NL- NL Number of leaves produced, PL- Petiole length, LL- Leaf length, FSE- First spathe emergence, NSWFF- Number of spikes with female flowers, NFF- Number of female flowers, SP- Spadix production per year.

compared to the other genotypes with the least being observed in MGD (10.2) in the fourth year (Fig. 2B).

NLD, NGBD, and IBD coconut genotypes produced significantly ($P \leq 0.05$) higher mean number of leaflets compared to those of MGD, and SGDVTT, which started from second to the fourth year. At year four, mean number of leaflets that ranged from 140.53 (MGD) to 170.74 (NLD) was observed (Fig. 2C).

There was a significant ($P \leq 0.05$) difference in the growth of petiole length among different coconut genotypes, with SGDVTT consistently producing shorter petiole lengths compared to the others. In the fourth year of the study, the average petiole lengths ranged from 26.75 (SGDVTT) to 38.82 cm (NLD) (Fig. 2D).

Additionally, the growth in leaf length for NLD, NGBD, MGD, and IBD was significantly ($P \leq 0.05$) higher than SGDVTT during the four-year study period. At year four, the average leaf lengths ranged from 165.35 cm (SGDVTT) to 260.95 cm (NLD), among the various coconut genotypes (Fig. 2E).

3.3. Reproductive characteristics

There was a significant difference ($P \leq 0.05$) in the time taken by the coconut genotypes to produce their first inflorescence. IBD, and NGBD were the earliest to flower, taking an average of 41.30 months, while NLD took the longest time (49.10) months to produce the first inflorescence (Fig. 3A).

Furthermore, NGBD, IBD, and SGDVTT had a significantly ($P \leq 0.05$) higher number of female flowers compared to NLD, and MGD. The highest number of female flowers was recorded in NGBD (38.15), while the least was observed in MGD (15.59) (Fig. 3B).

The total number of spikelets in an inflorescence includes both male and female flowers. NGBD had a significantly ($P \leq 0.05$) higher number of spikelets compared to the other genotypes. The observed total number of spikelets ranged from 16.35 (SGDVTT) to 23.87 (NGBD) (Fig. 3C).

The number of spikelets with female flowers for each coconut genotype (Fig. 3D) was also observed. Significant ($P \leq 0.05$) differences were observed between the genotypes. The highest number of spikelets with female flowers was observed in NGBD (17.25), while the least was in MGD (7.13) (Fig. 3D).

The annual mean number of spadices or inflorescences emerging from the coconut palms varied significantly ($P \leq 0.05$) among the genotypes, ranging from 9.38 (SGDVTT) to 15.26 (NGBD). On average, NGBD, and IBD produced more than one spadix per month compared to SGDVTT, NLD, and MGD (Fig. 3E).

Additionally, the length of peduncle measured varied significantly ($P \leq 0.05$) among the genotypes, ranging from 15.78 cm (SGDVTT) to 28.65 cm (NGBD). NGBD, and IBD had significantly ($P \leq 0.05$) longer peduncle while the shortest was produced by MGD (Fig. 3F).

3.4. Correlation between vegetative and reproductive characteristics

A strong and positive correlation between stem girth and time taken for flowering among the different coconut genotypes was observed. The correlation coefficient ranged from 0.25 (MGD) to 0.92 (NGBD) (Table 2).

Correlation between the number of leaves emitted, and number of female flowers produced in all coconut genotypes was positive and significant. Strength of the correlation varied among the genotypes, with the strongest correlation observed in IBD ($r = 0.87$) and the weakest in MGD ($r = 0.55$) (Table 2).

Following a similar trend, positive and significant correlation between leaf length, and the number of female flowers produced among the coconut genotypes was noticed. The correlation difference reflected among all genotypes, with the strongest correlation observed in IBD ($r = 0.95$) and the weakest in MGD ($r = 0.50$) (Table 2).

A significant and positive correlation was observed between the number of female flowers and the number of spikelets with female flowers among the coconut genotypes. Table 2 shows that the correlation strengths varied among the genotypes, which ranged from

Genotype	Stem girth (cm)	Leaf production	Petiole length (cm)	Leaf length (cm)	Number of leaflets	First inflorescence	Spikelet/ Spadix	Spikelet with female flowers	Number of female flowers	Number of spadices/year	Peduncle length (cm)
SGDVTT	68.24	15.12	26.42	165.36	150	41	16	12	24	11	23
NLD	105.25	12.09	38.37	260.21	170	48	18	9	22	9	23
NGBD	80.24	14.06	36.47	260.11	160	39	23	18	28	12	28
MGD	72.16	11.18	35.13	175.21	140	45	15	8	15	8	15
IBD	81.63	14.91	37.15	285.32	165	39	16	14	28	12	22

Fig. 4. Performance in selected agronomic traits by coconut genotypes. Colours represent performance trait by the coconut genotypes in relation to each other. Deep green = greatest, Yellow = intermediate, Red = least, Light green = second greatest in relation to deep green. SGDVTT = Sri Lankan Green Dwarf x Vanuatu Tall, NLD = Niu Leka Dwarf, NGBD = New Guinea Brown Dwarf, MGD = Malayan Green Dwarf, IBD = Indonesian Brown Dwarf.

0.56 (MGD) to 0.85 (IBD).

The number of spadices produced, and number of female flowers showed strong correlation that ranged from 0.82 (NGBD) to 0.89 (NLD) (Table 2).

4. Discussion

Based on differences observed in stem girth, annual leaf production, petiole length, leaf length, and number of leaflets among the coconut genotypes under the same environment (Fig. 4), it is expected that there is genetic variability present, which is consistent with earlier reports by Ref. [31]. This genetic variability could be attributed to differences in anatomy and morphology, which control how the palms develop, function, and respond to both internal and external stress factors [32], despite the palms being cultivated under the same environmental conditions. NLD coconut genotype consistently produced the largest stem girth throughout the study period (Fig. 2A). This characteristic may potentially be beneficial in facilitating water uptake and accumulation for use during drought periods [33]. This observation surmises that the NLD genotype could potentially be bred into a drought tolerant palm. We must however, state that a study on the physiology and anatomy of the NLD genotype is needed to further elucidate our observation and this is how our current study is limited.

The number of leaves produced by coconut palms is an important parameter as it influences the palms' growth rate and photosynthetic capacity [34]. In the first two years, leaf production was almost the same among the genotypes, but differences were observed after this period, which could be attributed to their physiological characteristics. The SGDVTT genotype produced the highest number of leaves after four years, although this was not significantly different from IBD, and NGBD (Fig. 2B). The slightly higher number of leaves produced by SGDVTT could be due to its tall parent (VTT). This finding is consistent with earlier studies by Refs. [34–36] who observed a higher number of leaves in tall coconut genotypes than in dwarf types. However, despite producing the highest number of leaves, the average leaf length of SGDVTT was the least. Moreover, previous research by Ref. [35] suggests that both leaf production and leaf lengths could be important indicators for selecting female parents in yield improvement programs. Therefore, leaf production and leaf length parameters could be used to differentiate coconut genotypes.

In contrast to SGDVTT, higher petiole lengths among NLD, NGBD, MGD, and IBD (Fig. 4), according to Ref. [37], is a better mechanism for adjusting source-sink imbalances and partly compensating transitory reserves in leaf petioles. The low number of leaflets observed in both SGDVTT, and MGD during the growth period resulted in small and less robust characteristics observed in these coconut genotypes in the field.

The time taken by coconut genotypes to produce their first inflorescence (spadix) is a significant parameter. Among the dwarf genotypes, IBD, and NGBD produced flowers earlier than the others, potentially due to their small stem girth. Conversely, NLD, which had the largest stem girth, delayed (>49 months) in producing its first inflorescence (Fig. 2A).

Total number of spikelets produced in an inflorescence is identified as a yield index [38]. The low number of spikelets with female flowers observed in MGD implies that this genotype is not likely to yield a high number of fruits and may not be suitable for future breeding programs. Our observation is also confirmed where MGD poorly performed in almost all its agronomic traits (Fig. 4). Fruit set in an inflorescence is dependent on the number of female flowers produced, highlighting the importance of the presence of female flowers [39]. The high number of spikelets with female flowers observed in NGBD, IBD, and SGDVTT from this study indicates that these coconut genotypes could be prolific fruit producers and may be considered in this regard in breeding programs. Reports by Ref. [40] suggest that the number of female flowers per spadix varies even within the same coconut palm, where the number of spadix that emerges correlates to growing conditions of the palm. The high number of female flowers may be partly due to more leaves emitted by the palms, culminating into high amount of photosynthates. Our result points to the fact that, NGBD, IBD, and SGDVTT could be more efficient in channeling photosynthates into flower formation. A submission by Ref. [41] suggests that the Brown dwarf coconut possesses a physiological mechanism that maintains higher rate of photosynthesis, coupled with a good potential for higher productivity irrespective of the environmental condition in which it develops. Variations observed in spadices produced among the coconut genotypes (Fig. 3E) indicate future differences in fruit production.

The study found a significant positive correlation between stem girth, and time to flowering, indicating that coconut palms with smaller stem girth tended to flower earlier. This result is consistent with a previous study by Ref. [42]. This observation is important in selecting and breeding palms with similar characteristics due to their potential to flower earlier.

Additionally, the study observed that coconut palms with higher leaf production tended to produce more female flowers and potentially, more fruits at later stages when the palms attain an optimum number of leaves. This is supported by a strong correlation between the number of leaves or leaf length, and the number of female flowers produced. The only exception to this trend was the MGD genotype. The number of spikelets with female flowers was also found to have a significant positive correlation with the number of female flowers produced per inflorescence. This suggests that the ability of the IBD genotype to produce many female flowers is dependent on the number of spikelets with female flowers (Table 2). This finding is consistent with [34].

We also found a strong positive correlation between the number of spadices produced by the palms, and the number of female flowers produced. This indicates that palms that produce more spadices are likely to produce more female flowers and, thus, more fruits.

5. Conclusion

In conclusion, our assessment of the selected agronomic traits has led to the identification of unique characteristics in each genotype, which could help cultivate palms that are suitable in specific environments. Variations noticed among the genotypes are likely

to continue and reflect in growth patterns, which will ultimately translate into yield differences among the selected palms. It is noteworthy to state that none of the palms under consideration showed symptoms of the lethal yellowing disease throughout the study period. We must however, state that the current study is limited to only one location, where the disease is endemic. Significant and positive correlations between number of leaves emitted, and number of female flowers produced were observed in all coconut genotypes except for the Malayan Green Dwarf. Malayan Green Dwarf produced the least number of spikelets with female flowers, suggesting that this genotype is not likely to be suitable for production. The small and less robust characteristics in both SGDVTT, and MGD in the growing period is likely to be ascribed to the rather low number of leaflets observed in these genotypes.

The current study, therefore, indicates that Niu Leka Dwarf, New Guinea Brown Dwarf, and Indonesian Brown Dwarf genotypes can be selected for future breeding and hybridization programs while the Malayan Green Dwarf should not be included. This study raises interesting questions into how selected agronomic practices could be channeled into improving flower production, which will translate into fruit formation for higher yields among selected coconut genotypes.

Data availability statement

The raw/processed data will be made available upon request.

CRediT authorship contribution statement

Christian Kofi Anthonio: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Linda Arhin:** Writing – review & editing. **Daniel Ansah Fianko:** Writing – review & editing. **Frederick Leo Sossah:** Writing – review & editing. **Emmanuel Andoh-Mensah:** Writing – review & editing. **Ndede Egya Yankey:** Writing – review & editing, Validation, Supervision, Resources, Investigation, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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