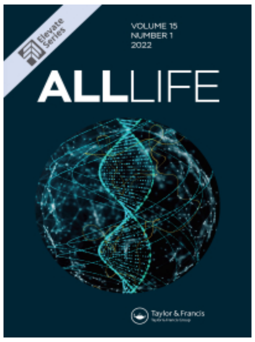

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Seasonal dynamics of *Elaeidobius Kamerunicus* in allopatric populations: comparative analysis from indigenous mainland and introduced oil palm ecosystems in Uganda's lake Victoria islands

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ABSTRACT

Oil palm (*Elaeis guineensis* L.), native to Africa but widely cultivated in Southeast Asia, is increasingly grown in Uganda, and pollination efficiency is critical for fruit set and oil yield. The study assessed the population and sexual diversity of the primary pollinator, *Elaeidobius kamerunicus* FAUST, in introduced hybrid plantations in Kalangala and natural stands in Bundibugyo. Pollinator weevils were sampled across both wet and dry seasons in 2022 and 2023, and data were analyzed using ANOVA and correlation tests in Minitab 17. Results revealed significant variation between sites, with higher populations in Kalangala (7,503 ± 8.682) compared to Bundibugyo (5,164 ± 5.829). Furthermore, females (6,636 ± 4.646) outnumbered males (6,032 ± 5.028), with a slightly higher concentration of females in the middle section of male inflorescences. Seasonal differences were evident, as the wet season supported slightly higher weevil populations relative to the dry season. Correlation analysis indicated a weak negative relationship between weevil abundance and weather variables, suggesting that cooler conditions suppress population growth. Overall, Uganda provides favorable conditions for pollinator weevil multiplication, particularly under moist climatic regimes, while extensive cold conditions limit population expansion. These findings highlight the importance of pollinator dynamics in sustaining oil palm productivity in diverse agro-ecological regions.

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KEYWORDS
Oil palm; pollination efficiency; *Elaeidobius kamerunicus*; seasonal variation; Uganda

Introduction

The oil palm (*Elaeis guineensis* Jacq.), a perennial monocot, thrives under the warm, humid conditions characteristic of tropical and subtropical regions (Paterson and Lima 2018). Although indigenous to Africa, *E. guineensis* has been extensively cultivated in Southeast Asia, particularly in Malaysia and Indonesia, due to its high commercial value (Amugoli et al. 2022). The predominant cultivated genotype, known as Tenera, is a hybrid derived from crossing the thick-shelled Dura and the shell-less Pisifera. Tenera palms exhibit enhanced oil yields due to a thicker mesocarp relative to their seed nuts. However, when seeds from Tenera hybrids are replanted, they undergo genetic segregation, resulting in progeny with variable fruit morphology. These segregants frequently exhibit reduced mesocarp thickness and consequently lower oil content, undermining the agronomic advantages of the original hybrid cross (John Martin et al. 2022).

Commercial oil palm (*Elaeis guineensis* Jacq.) cultivation in Uganda predominantly utilises introduced hybrid Tenera seed nuts, which result from controlled crosses between Dura and Pisifera parental lines and are valued for their superior oil yield due to an expanded mesocarp. Indigenous or natural oil palm populations have historically grown along the Uganda–Democratic Republic of Congo border, over time.

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Many of these plants express phenotypes characteristic of the Dura type, notably reduced mesocarp thickness and correspondingly low oil content (Ddamulira et al. 2020).

Although large-scale oil palm cultivation is a recent agricultural development in Uganda, the crop has rapidly gained prominence as a key economic and oil-producing commodity, particularly within Kalangala islands. Its expansion has contributed to notable improvements in household income among smallholder farmers and a reduction in national dependence on imported vegetable oil. Nevertheless, overall production remains below optimal levels (Ddamulira et al. 2024).

Due to its perennial growth habit, *E. guineensis* is often subjected to several biotic and abiotic constraints that cumulatively affect yield performance (Cock et al. 2016). One critical limitation is suboptimal fruit set, primarily attributed to inadequate pollination. As an entomophilous species, the oil palm relies predominantly on *Elaeidobius kamerunicus* Faust (EK), a specialised pollinator weevil, for effective pollination and subsequent fruit development.

The population dynamics of EK are influenced by several ecological and agronomic factors. One of the constraints is the phenology of high-yielding oil palm varieties, which often exhibit a reduced ratio of male inflorescences. These male inflorescences serve as critical sites for EK feeding and reproduction; thus, their scarcity directly reduces EK population viability (Prasetyo et al. 2014). The environmental parameters, such as temperature, humidity, and floral scent composition, also affect the abundance of EK, as well as their behavioural responses to volatile organic compounds emitted by palm inflorescences (Yahya et al. 2012).

Genetic bottlenecks further exacerbate vulnerability, and reports from Malaysia highlight a significant decline in fruit set linked to dwindling EK populations compromised by entomopathogenic nematodes due to limited genetic diversity, which undermines their adaptability to environmental stressors (Mohamad et al. 2023).

The female inflorescences can yield between 500 to 4,000 fruits per bunch, with an average bunch weight ranging from 5 to 50 kg, contingent on successful pollination of approximately 30% to 60% of flowers. In Uganda, the foundational hybrid Tenera seed nuts introduced for commercial cultivation in Kalangala originated from Malaysia (Amugoli et al. 2022). On the Lake Victoria islands, EK populations are geographically isolated from their mainland counterparts, forming allopatric groups that may exhibit distinct genetic and ecological characteristics due to limited gene flow.

Several yield-related anomalies, including uneven ripening, poor fruit set, and increased frequencies of parthenocarpic fruit formation that collectively limit optimal oil palm productivity in both nucleus estate plantations and outgrower plots, have previously been reported in Kalangala (Masika et al. 2020). To address the challenges, there is a need to quantify the population of oil palm pollinator weevils across the Lake Victoria islands and the mainland to establish any potential link between observed physiological disorders in oil palms and the oil palm weevil abundance. Pollinator weevil density is positively correlated with oil palm fruit set, which directly influences both yield and extraction efficiency (Kouakou et al. 2018). As weevils traverse the oil palm inflorescences, pollen grains adhered to their bodies and are inadvertently deposited onto receptive female flowers, thereby facilitating pollination. Consequently, higher weevil populations are associated with increased rates of pollination and fruit formation (Mohamad et al. 2021).

Moreover, isolated natural oil palm plantations exist along the Uganda-Congo border, extending geographically from Kisoro District in the southwest to Koboko in the northwest. These areas present a unique opportunity for comparative ecological analysis of pollinator activity and population genetic structure. The natural Dura oil palm stands have undergone prolonged pollination by indigenous weevils (*Elaeidobius kamerunicus*), presumed to have originated from the Congo Basin. The Democratic Republic of Congo has the highest acreage of natural oil palm trees per hectare in Africa (Verheye 2010), suggesting a well-established ecological interaction between these palms and their pollinators.

Despite the establishment of commercial oil palm plantations in Kalangala District on the Lake Victoria islands and the persistence of naturally occurring populations in Bundibugyo District along the Uganda–Congo border, the population density and sexual dimorphism of *Elaeidobius kamerunicus* remain unquantified in these contrasting agroecological zones. This study was therefore undertaken to systematically evaluate the abundance and sex ratios of *E. kamerunicus* within introduced hybrid Tenera plantations in Kalangala and natural Dura stands in Bundibugyo. Quantifying pollinator populations across these environments addresses a critical knowledge gap, as pollinator density is directly linked to fruit set and oil yield. The findings provide an empirical basis for developing strategies to optimise pollination efficiency, enhance yield stability, and reduce Uganda's reliance on imported vegetable oil.

Materials and methods

Study area

The study was carried out in Kalangala and Bundibugyo Districts in Uganda. Kalangala and Bundibugyo districts are found in two different agroecological regions and represent the introduced and natural oil palm plantations, respectively. Kalangala is an island district comprising of different islands on Lake Victoria in the southwestern part of Uganda. The district has ferralitic sandy loamy soils and receives between 1,125 to 2,090 mm of rainfall with temperatures ranging from 17.5 °C to 27.5 °C annually. The district has 70,589 people according to the National Housing and Population Census, 2024, almost all of whom depend directly or indirectly on oil palm farming. This district is primarily planted with hybrid oil palm plants. Bundibugyo District is located in Western Uganda on the northern slopes of Mount Rwenzori. The district is located at the intersection between the tropical rainforest climate of the Democratic Republic of Congo and the Savannah climatic conditions of Uganda. The District receives an average annual rainfall of 100 to 2,228 mm, while temperatures range between 13.5 to 27.7 °C. The district mainly has alluvial soils from the mountain. Natural oil palm plantations have existed in this area for a long time because of the spillovers from the Democratic Republic of Congo.

Experimental design

The total study plot measured 5 hectares within the Kalangala oil palm estate and over 20 hectares in the natural fields in Bundibugyo. The selected plots in Kalangala were based on the management strategies used and the age of the palms. We targeted palms that were 10 years old to ensure uniformity in Kalangala, while in Bundibugyo, the ages of the natural palms varied from 10 to 15 years. The palms were systematically selected by marking every tenth palm in a line and skipping four lines before marking the next palm on the next line. Eighty-seven hybrid (Tenera) and 150 (Dura) palms were marked in Kalangala and Bundibugyo, respectively, where data were collected throughout the study period.

Determination of sex and population of pollinator weevils (EK)

Data were collected during the dry (February and March) and wet (May and June) seasons of 2022 and 2023 calendar years, and the population and sex of EK were determined according to Soetopo (2020) and Chiu et al. (1986) on male inflorescence. The EK were collected from a male inflorescence at anthesis. The male inflorescence contains approximately 100 to 300 spikeletes each of length 10–30 cm, and contains on average 950 male florets (Janick and Paull 2008). Data were collected on the number of EK (males and females) at the different sections (bottom, middle and top), and the number of spikelets per inflorescence. The selected spikelets were securely harvested using a pair of secateurs, and the number of spikelets per inflorescence was recorded. The data were collected from the identified fields in the wet and dry seasons for two consecutive years. A total of nine spikelets were collected from each male inflorescence from 07:00 a.m. to 11:00 a.m., where three spikelets were collected each from the bottom, middle and top of a male inflorescence during anthesis. The sampled spikelets were stored in well-labelled sealable packs and transported to the entomology laboratory at the National Crops Resources Research Institute (NaCRRI) for population and sex determination. The pollinator weevils were sorted into males and females following the presence or absence of setae on the elytra and the size of the proboscis and thorax with the aid of a magnifying lens. The total population of the pollinator weevils was determined according to Wahid and Kamarudin (1997). The number of pollinator weevils per bunch was determined by calculating the average number of pollinator weevils per spikelet and then multiplying by the number of spikelets per inflorescence.

Data analysis

The mean data were analysed using analysis of variance (ANOVA) through Minitab 17 Statistical Software. Differences in the mean population of pollinator weevils were assessed at a 95% confidence interval and further distinguished using Tukey's multiple comparison test. The associations between weevil population and weather variables (temperature and humidity), both across sexes and overall, were evaluated using Pearson's correlation coefficient (r). The graphical visualisation was conducted using the R statistical computing environment (version 4.5.1; R Core Team, 2025).

Results and discussion

The number of pollinator weevils in hybrid oil palm varieties (in Kalangala district) was generally high (7503 ± 8.682) compared to the pollinator weevils from natural oil palm plantations (in Bundibugyo) (5164 ± 5.829), Table 1. The differences in the means of the pollinator weevils for the allopatric populations were statistically significant $F(1,1041) = 94.91$, $p < 0.001$), as separated by the Tukey Pairwise comparison. The limited management practices applied to the natural oil palm plantations may explain the lower number of pollinator weevils in Bundibugyo compared to the allopatric oil palm weevil populations in the well-managed plantations of introduced materials in the Lake Victoria islands of Kalangala. Low management levels may expose pollinators to parasites like nematodes, although the incidence of parasitic nematodes on oil palm pollinator weevils is a subject of another study. According to Gintoron et al. (2023), low management strategies and biotic stressors like nematodes are important factors affecting the pollinator weevil population in Malaysia.

Furthermore, oil palm plantations in Bundibugyo are commonly intercropped with crops such as cocoa, coffee, and others. These companion crops are frequently sprayed with pesticides, which may inadvertently harm vital oil palm pollinators, a phenomenon similarly documented in Ghana (Umeh et al. 2022). Similarly, there were fewer pollinator weevils recorded in the dry season (February and March) (5690 ± 6.219), compared to the wet season (May and June) (6977 ± 8.810). The differences in the means of the pollinator weevils in the wet and the dry seasons was statistically significant ($p < 0.001$). This may be attributed to the high numbers of male inflorescences observed in the rainy season, which is a source of food and a breeding ground for the oil palm pollinator weevils. Similar findings were reported by Fatihah et al. (2019) and Rizuan et al. (2013) that higher numbers of the oil palm male inflorescences and spikelets positively correlated with a greater abundance of oil palm pollinator weevils. This is also in line with other studies, which reported linear relationships between higher rainfall distributions, the number of rainy days, and humidity with the number of pollinator weevils (Zulkefli et al. 2020; Gintoron et al. 2023). These studies reported a high population development of EK during the rainy season, which is shown in this study. Other entomological studies in Uganda have also shown a high abundance of rice insects in the rainy season compared to the dry season (Masika et al. 2017).

Table 1. Sexual, seasonal and temporal variation of pollinator weevils in the study areas.

Variable	State	N	Mean	Total	StDev
District	Bundibugyo	521	9.912	5164	5.829
	Kalangala	522	14.374	7503	8.682
Female	Bundibugyo	521	5.251	2736	3.696
	Kalangala	522	7.471	3900	5.595
Male	Bundibugyo	521	4.664	2430	4.309
	Kalangala	522	6.900	3602	5.747
All weevils	Dry	522	10.900	5690	6.219
	Wet	521	13.392	6977	8.810
Female	Dry	522	6.358	3319	5.116
	Wet	521	6.367	3317	4.613
Male	Dry	522	4.546	2373	3.048
	Wet	521	7.023	3659	6.464
All weevils	BOTTOM	347	11.398	3955	7.321
	MIDDLE	344	13.119	4513	8.210
	TOP	352	11.929	4199	7.534
Male	BOTTOM	347	5.369	1863	4.897
	MIDDLE	344	6.422	2209	5.732
	TOP	352	5.568	1960	4.887
Female	BOTTOM	347	6.035	2094	4.609
	MIDDLE	344	6.698	2304	5.111
	TOP	352	6.358	2238	4.867

There was a high number of female (6,636 ± 4.646) compared to the male (6,032 ± 5.028) oil palm pollinator weevils in both the island and mainland study areas. Although in nature the sexual variation is variable, the observed numbers of female pollinator weevils compared to the males can be attributed to the high life expectancy of the females compared to the males. A study by Tuo et al. (2011) on the biology of *Elaeidobius kamerunicus* and *Elaeidobius plagiatus* (Coleoptera: *Curculionidae*), the main pollinators of oil palm in West Africa, showed that female EK have a higher life expectancy compared to the males, as is for most organisms in nature. The higher number of female compared to male pollinator weevils is of evolutionary importance because they lay eggs for future generations. Therefore, the higher their numbers, the higher the progeny and the pollination efficiency (Mohamad et al. 2022). Furthermore, since some female pollinator weevils can hatch by parthenogenesis, it may not be surprising to have higher numbers of females compared to male pollinators (Zulkefli et al. 2020).

There was a slightly higher mean of pollinator weevils in the middle (13.119 ± 8.210) part of the inflorescence compared to the top 11.398 ± 7.321 and the bottom (11.929 ± 7.534). The differences were statistically significant ($p = 0.011$). This may be attributed to the fact that the pollinator weevils often move very fast and hide away from intruders, and most often away from the light. The pollinator weevils therefore, move from the spikelets from the top and the bottom parts of the inflorescence to the middle part. Further, there were higher numbers of female pollinator weevils (2304 ± 5.111) in the middle section of the male inflorescence compared to the male pollinator weevils (2209 ± 5.732). This could be due to the smaller sizes of female pollinator weevils and the high mobility of the female pollinator weevils compared to the males (Ismail et al. 2020).

A weak negative correlation was observed between the weevil population and average humidity (? = −0.248, $p = 0.947$) and average temperature (? = −0.225, $p = 0.947$) across both study sites. This pattern was consistently illustrated in Figure 1, which demonstrated a weak association between oil palm weevil

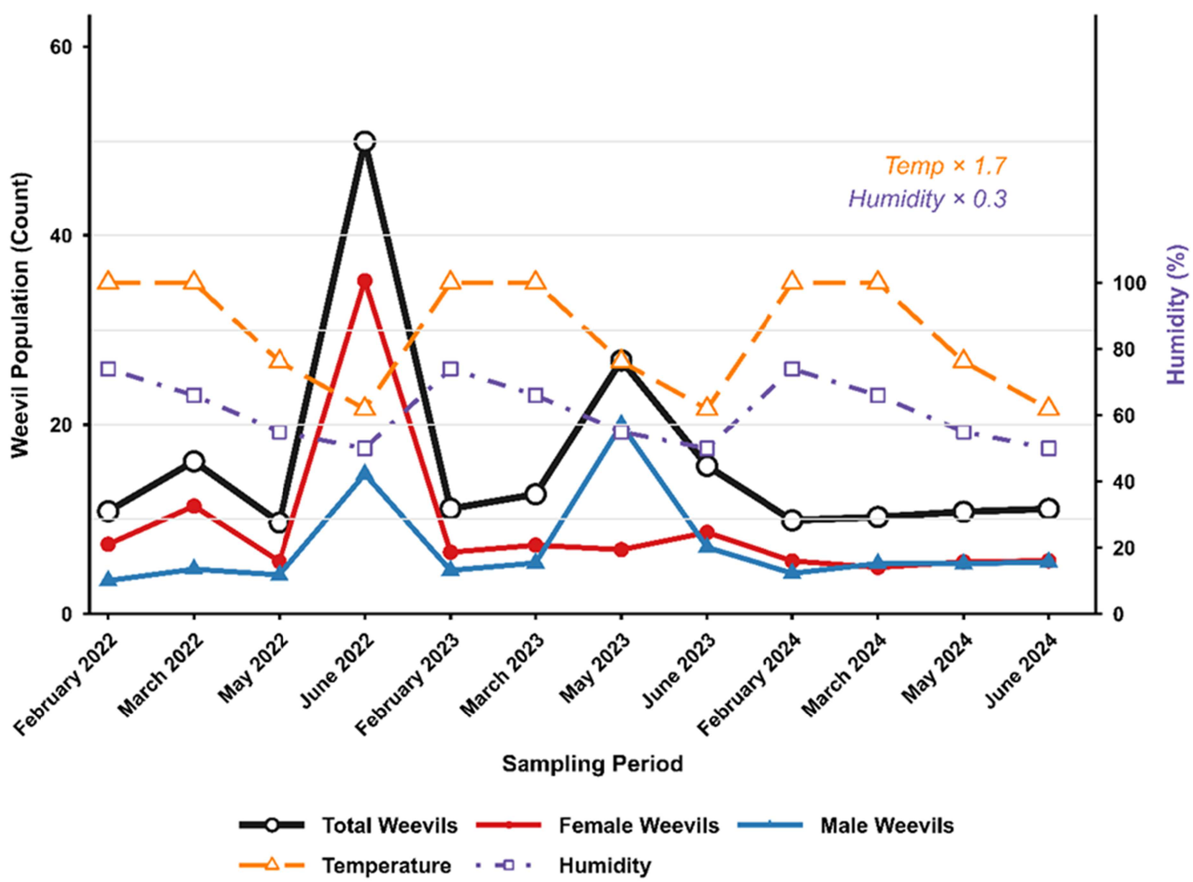

Figure 1. Correlation patterns between oil palm weevil population dynamics and key meteorological parameters across the study sites. Note: To facilitate direct comparison with weevil abundance, environmental variables were proportionally rescaled (temperature multiplied by 1.7; relative humidity multiplied by 0.3) and plotted on the same axis.

abundance and ambient temperature. The limited relationship is likely attributable to the relatively narrow thermal gradient observed across the two study sites, both situated within equatorial tropical zones where temperature fluctuations are minimal (Verheye 2010). Similarly, the modest negative correlation observed between relative humidity and oil palm weevil abundance may be attributed to the limited variability in humidity across the study sites. The consistently high and stable moisture conditions typical of equatorial tropical environments likely reduced the potential for detecting stronger ecological associations (Gintoron et al. 2023).

Conclusion

Population assessments of *Elaeidobius kamerunicus*, a key oil palm pollinator weevil, revealed significantly lower densities within intercropped, naturally occurring oil palm stands compared to the introduced, commercially managed monoculture plantations on the Lake Victoria islands. This disparity is hypothesised to result from unregulated agrochemical application and minimal agronomic intervention within the natural populations, which may negatively affect EK habitat suitability and survivorship.

Seasonal fluctuations in EK abundance were also observed, with markedly higher populations recorded during the wet season (May–June) relative to the dry season (February–March). This temporal variation appears strongly correlated with the phenological availability of male inflorescences, which serve as a primary feeding and breeding ground for EK. Female EK weevils slightly outnumbered males in sampled populations. Although natural sex ratio fluctuations occur, this female predominance may be due to the species' ability to reproduce parthenocarpically. Given the ecological importance of EK in facilitating oil palm pollination, there is an urgent need to assess the genetic diversity of the allopatric weevil populations across the Lake Victoria islands.

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Author contributions

CRediT: **Fred Bwayo Masika:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Validation, Visualization, Writing – original draft, Writing – review & editing; **Amugoli Moses Otuba:** Validation, Writing – review & editing; **Mahipal Singh Kesawat:** Supervision, Writing – original draft, Writing – review & editing; **Alex Asiimwe:** Writing – original draft, Writing – review & editing; **Bidget Baguma:** Writing – original draft, Writing – review & editing; **Titus Alicai:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing; **Swati Manohar:** Writing – original draft, Writing – review & editing; **Gabriel Ddamulira:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing.

Disclosure statement

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Data availability statement

The data that support the findings of this study are available in Mendeley Data at https://data.mendeley.com/datasets/35frk3nxd5/1.

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