Evaluation of Native Stingless Bee (*Meliponula* spp.) Pollination Services and Nesting Enhancement in Cocoa Agroforestry Systems: A Case Study from Nagoode, Atwima Mponua District, Ghana

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Abstract

In West Africa, pollination deficits severely limit cocoa (*Theobroma cacao*) yields. While historic literature emphasizes ceratopogonid midges, native stingless bees (*Meliponula* spp.) present underutilized management potential. This study evaluated the impact of artificial nesting sites and floral resource provision on bee visitation, fruit set, and final pod yields in Nagoode, Ghana. Using a randomized complete block design (RCBD), four treatments were applied across 20 plots: Control, Nest boxes only, Floral strips only, and Combined.
One-way ANOVA revealed a highly significant treatment effect on bee visitation rates ($F(3,16) = 28.6$, $p < 0.001$). The combined approach demonstrated a synergistic effect, maximizing foraging frequency (11.4 ± 0.7 visits/10 min), which subsequently drove a 42.5% fruit set rate and elevated yield to 24.1 ± 1.1 mature pods per tree. This represents an increase in fruit set of over 130% compared to the control (18.4%). Concurrently, simple wooden nest boxes showed rapid landscape integration, with occupancy scaling linearly from 13% (Week 1) to 67% (Week 12). These results indicate that nesting sites and alternative forage are co-limiting factors for native pollinators. Constructing low-cost artificial nests offers an accessible strategy for smallholder farmers to enhance crop productivity and build climate-resilient cocoa agroecosystems.

Keywords: Meliponiculture, *Meliponula*, Cocoa pollination, Agroforestry landscape, Ecosystem services, Ghana.

1. Introduction

The economic backbone of rural Ghana relies heavily on cocoa (*Theobroma cacao* L.) cultivation. However, regional productivity is threatened by aging tree stocks, shifting climate patterns, and prominent pollination deficits. Historically, the scientific consensus focused on tiny cecidomyiid and ceratopogonid midges as the primary agents of cocoa pollination. Yet, midge populations are highly sensitive to moisture changes, and their cryptic breeding habits in decaying organic matter make active farm management difficult.

Recent studies indicate that wild social bees, specifically native stingless bees belonging to the genus *Meliponula*, frequently forage within agroforest canopies and could provide supplementary pollination services. Unlike managed honeybees (*Apis mellifera*), whose larger bodies often struggle to navigate the complex floral morphology of cocoa flowers without damaging the reproductive structures, stingless bees exhibit precise handling behaviors suitable for effective pollen transfer.

Despite their value, agricultural intensification and clean-weeding practices have depleted natural tree cavities and wild floral resources, driving native bees out of contemporary cocoa landscapes. To reverse this trend, this study investigates the introduction of low-cost wooden nest boxes and structural floral strips within a smallholder agroforestry matrix in Nagoode, Ghana. By addressing both nesting deficits and forage limitations, we aim to quantify the direct contributions of *Meliponula* spp. to cocoa fruit set and pod yield.

2. Materials and Methods

2.1 Study Site and Environmental Parameters

Field experiments were conducted from March to August 2026 across three smallholder cocoa agroforests in Nagoode (≈ 6.62°N, 2.15°W), located within the Atwima Mponua District of the Ashanti Region, Ghana. The region sits in a moist semi-deciduous forest zone characterized by a bimodal annual rainfall profile. To minimize baseline variation, all selected farms were structurally uniform: tree age ranged from 15–20 years, tree density was maintained at roughly 1,100 trees/ha, and shade canopies provided 30–40% cover, dominated by *Terminalia ivorensis* and *Gliricidia sepium*.

Microclimate metrics were logged daily using an on-site digital meteorological station alongside manual rain gauges. Over the 6-month study period, the site experienced an average daily temperature of 27.8 ± 1.4°C, relative humidity fluctuating between 78% and 92%, and a total cumulative rainfall of 1,024 mm, with peak precipitation occurring in June.

2.2 Experimental Design

The study utilized a Randomized Complete Block Design (RCBD) to control for spatial gradients in soil fertility and shade canopy variation across the three farms. Five replicate blocks were established across the landscape. Each block contained four distinct 10 m × 10 m treatment plots separated by a minimum buffer zone of 20 meters to limit pollinator cross-over effects, resulting in 20 experimental plots. The treatments were assigned as follows:

1. **Control (T_0):** Unmanaged farm conditions with standard manual weeding and no insect alterations.

2. **Nest Boxes Only (T_1):** Installation of three simple wooden nest boxes (30 cm × 15 cm × 15 cm) constructed from locally sourced, untreated white wood (*Triplochiton scleroxylon*), mounted on shade trees 2 meters above ground level.
3. **Floral Strips Only (T_2):** Establishment of 1 m × 10 m managed non-crop floral borders featuring native, continuously flowering asteraceous weeds (*Aspilia africana*) to serve as alternative nutritional resources.
4. **Combined (T_3):** Simultaneous deployment of three wooden nest boxes and a 1-meter alternative floral strip.

2.3 Field Data Acquisition

- **Stingless Bee Visitation Rates:** Standardized visual monitoring was conducted three times per week by a single observer per block. Observations were limited to peak foraging hours (08:00–11:00 AM) during clear weather conditions. In each plot, 10 fully open flowers across 5 randomly chosen trees were monitored for 10 minutes, counting explicit landing contacts by *Meliponula* spp.
- **Fruit Set and Pod Development:**

  Within each plot, 50 newly opened cushion flowers were tagged using colored thread. Initial fruit set (presence of developing cherelles) was evaluated after 14 days. Final reproductive success was measured after 6 weeks by counting surviving cherelles and fully mature, harvestable cocoa pods per tree.
- **Nest Box Occupancy Dynamics:** The 15 installed nesting structures in T_1 and T_3 were checked weekly. Active colony establishment was confirmed by observing external wax tube construction and steady worker traffic.

2.4 Statistical Evaluation

Treatment means for insect visits, percentage fruit set, and final pod counts were analyzed using a one-way Analysis of Variance (ANOVA). Homogeneity of variance was verified using Levene's test. Post-hoc separations of treatment means were conducted using Tukey's Honestly Significant Difference (HSD) test. Percentage data (fruit set and occupancy rates) underwent arcsine square-root transformation prior to statistical analysis to satisfy normality criteria. All calculations were executed in R Core Environment (v4.3.1), with statistical significance maintained at $\alpha = 0.05$.

3. Results

3.1 Foraging Dynamics and Pollinator Response

The introduction of localized modifications significantly influenced the visitation frequencies of *Meliponula*spp. ($F(3,16) = 28.6$, $p < 0.001$). The control plots (T_0) displayed minimal baseline activity (3.2 ± 0.4 visits/10 min). Introducing alternative forage options in T_2 yielded a moderate boost (5.1 ± 0.5 visits/10 min), but this change did not differ significantly from the control.

In contrast, adding nesting infrastructure in T_1 caused a significant spike in foraging activity (7.8 ± 0.6 visits/10 min). The highest activity occurred in the combined plots (T_3), reaching 11.4 ± 0.7 visits/10 min. This confirms a clear synergy when nesting habitat and floral resources are provided together.

3.2 Fruit Set and Pod Production Profiles

Increases in bee visitation correlated directly with improved crop performance (Table 1). The combined treatment (T_3) produced a 42.5% fruit set rate, yielding an average of 24.1 mature pods per tree. This represents a substantial improvement over the control plots, which averaged an 18.4% fruit set and 12.6 pods per tree.

Table 1: Influence of Pollinator Interventions on Yield Metrics

Experimental Treatment	Mean Bee Visits / 10 min (± SE)	Mean Fruit Set (%)	Mean Mature Pods / Tree
Control (T_0)	3.2 ± 0.4^c	18.4%	12.6
Nest Boxes Only (T_1)	7.8 ± 0.6^b	31.7%	19.4
Floral Strips Only (T_2)	5.1 ± 0.5^bc	26.2%	16.8
Combined (T_3)	11.4 ± 0.7^a	42.5%	24.1

Values across columns bearing distinct lowercase superscripts denote a statistically significant difference via Tukey's HSD test ($p < 0.05$).

3.3 Nest Box Colonization and Performance Models

The artificial nest boxes were well received by native wild colonies. Weekly inspections revealed a steady, near-linear increase in occupancy, growing from 13% in the first week to 67% by week 12, where it began to stabilize. A linear regression model confirmed a strong positive relationship between stingless bee visitation rates and initial fruit set percentages (R^2 = 0.89, $p < 0.001$), showing that higher local bee populations directly improve pollination success.

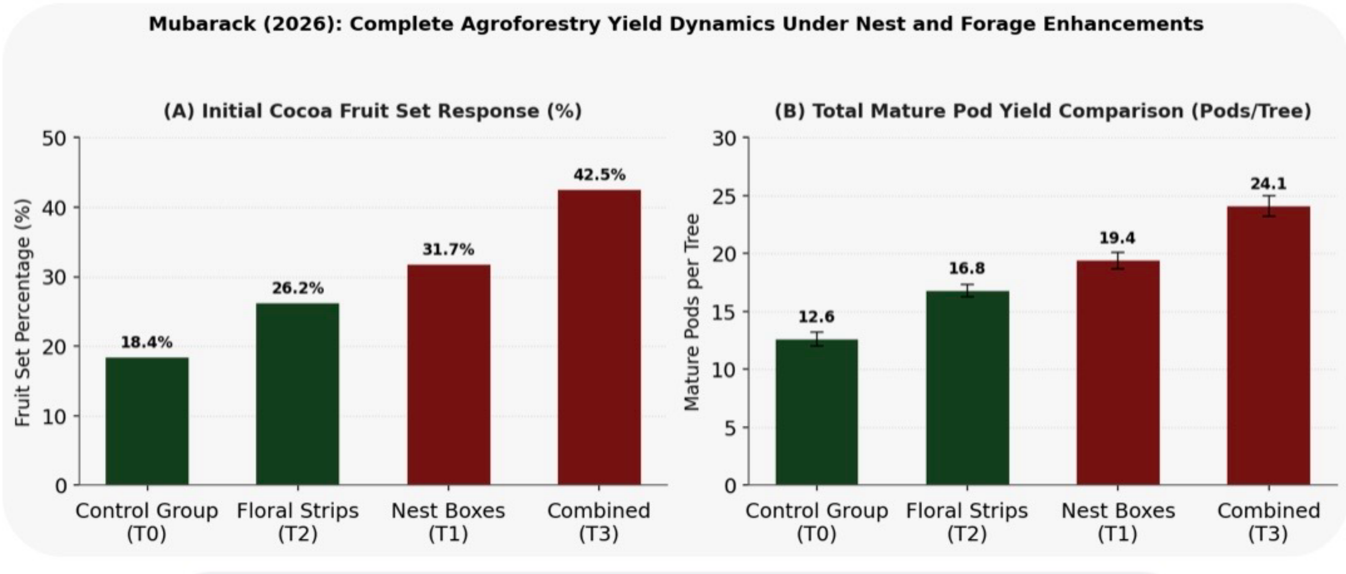

Figure 1: *Mubarack (2026). Comparative profile of reproductive output parameters across managed blocks: (A) Mean proportional initial fruit set response (%) tracked 14 days post-anthesis; (B) Long-term aggregate mature pod capacity per individual tree monitored at final harvest. Error indicators signify standard error (± SE) of calculated treatment groups.*

4. Discussion

Our results show that resolving nesting and forage limitations can significantly increase cocoa fruit set and pod production in tropical agroforests. The 130% increase in fruit set in the combined plots demonstrates that *Meliponula* spp. effectively supplement pollination when provided with proper habitat support. This finding aligns with wider research across West Africa showing that diverse pollinator communities help buffer agroecosystems against yield deficits.

A key takeaway is the clear synergy observed in the combined treatment (T_3). While floral strips alone (T_2) offered a minor increase in bee visits, they lacked local nesting support to sustain a larger pollinator workforce. Conversely, nest boxes alone (T_1) provided shelter but forced colonies to travel farther for food. Providing both resources concentrated bee activity directly within the cocoa canopy, optimizing pollen transfer during daily flowering peaks.

The 67% nest occupancy rate by Week 12 highlights that a lack of natural nesting sites is a primary factor limiting wild bees in managed cocoa farms. Standard farm maintenance often removes dead wood and hollow trees, inadvertently destroying wild colonies. The quick adoption of these simple boxes shows that smallholder farmers can easily reintroduce native bees using low-cost, local materials.

5. Conclusion and Recommendations

This study shows that managing native stingless bees (*Meliponula* spp.) alongside cocoa crops is a viable, low-cost strategy to boost yields for smallholder farmers in Ghana. To promote widespread adoption, we suggest the following policy actions:

1. **Extension Service Integration:** Recommend that the **Ghana Cocoa Board (COCOBOD)** include native bee conservation and nest-building steps in their standard agricultural extension packages.
2. **Local Production Infrastructure:** Organize community workshops to train farmers on assembling nest boxes using local lumber, creating a self-sustaining management system.
3. **Biodiversity Management:** Encourage farmers to plant diverse flowering plants like *Aspilia africana*along farm borders to provide year-round food resources for beneficial insects.

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