

Phaseolus vulgaris Production Attributes as Affected by Termite Mound Soil *Apis mellifera* Interactions at Dang (Ngaoundere, Cameroon)

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Abstract Investigations were carried out to evaluate the influence of termite mound soil and insects on growth, pod and seed yields attributes of *Phaseolus vulgaris* var brown seeds in Ngaoundere. The experiment was conducted in a randomized complete block design consisting of three treatments, each of which was repeated three times: subplots receiving termite mound soil (PTT), subplots receiving chemical fertilizer (PTP) and subplots receiving neither termite mound soil, nor chemical fertilizer (PTN). Four other treatments were set up: two treatments, each consisting of 120 flowers and differentiated by the presence or absence of insect protection from flowers, and two treatments consisting of 200 flowers protected from insects and then intended to be discovered, visited once by *A. mellifera* and protected again, and 100 flowers protected from insects and then intended to be exposed and protected again, with no visits from insects or any other organism. Through the pollination efficiency of a floral visit, *A. mellifera* contributed to increased fruiting rate, number of seeds per pod and percentage of normal seeds by 15.03%, 14.59% and 28.18% respectively. Termite mound soil increased the fruiting rate, number of seeds and percentage of normal seeds by 18.75%, 1.96% and 3.31% respectively. The combined effect of termite mound soil and *Apis mellifera* increased the fruiting rate, number of seeds per pod and percentage of normal seeds by respectively 10.52 %, 20.36% and 12.67%. Termite mound amended soil and the installation and preservation of *A. mellifera* nests at near or within *P. vulgaris* field could be recommended to improve the production of this crop legume.

Keywords: *Phaseolus vulgaris*, *Apis mellifera*, termite mound soil, pollination, flowers, yield

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1. Introduction

Opposite to conventional agriculture, organic farming is one of the ways in which we can contribute to meeting several challenges in terms of food security, biodiversity protection producer and consumer health [1]. Hunger is a scourge that affects developing countries, where living conditions reduce the food security [2]. One of the objectives of agronomic research is to optimize yields [3] of population, needs are to be met. To overcome this problem, it is important to know factors that can improve plant mineral nutrition such as termite around soils [4], or insect pollinators that can increase fruits and seeds production [5].

The exploitation of termite mound soils and insect pollinators features is very poorly documented in African agricultural programs [6,7]. *Phaseolus vulgaris* or

common bean is an annual, erect and voluble crop of the Fabaceae family [8], native to Central and South America [9]. Seeds are rich in minerals, vitamins and proteins [10]. The plant offers advantages in maintaining soil fertility and developing efficient cropping systems, because of their ability to establish symbiosis with soil bacteria of the genus *Rhizobium* [11,12]. Commonly known as the "meat of poor", beans are a staple food for almost 500 million people, due to their high protein content [13].

In Cameroon, apart from the evaluation of the impact of an organic fertilizer (chicken manure) and the flowering insect *Xylocopa olivacea* on *Phaseolus vulgaris* yields [14], no research has yet been conducted on the interaction between termite mound soil and *Apis mellifera* on the yield of this plant. The present work is a contribution to the improvement of our knowledge on the interaction between *P. vulgaris*, termite mound soil and flower-feeding insects for their optimal management. In this research, the assessment of the single or combined impact

of termite mound soil and *A. mellifera* on plant growth and yield attributes, as well as the diversity of insects visiting *P. vulgaris* flowers and their effect on the plant production are explored.

2. Materials and Methods

2.1. Site and Biological Materials

Investigations were conducted from August 13 to October 15, 2022 at Dang, within the Ngaoundere III Council, Vina Division, Adamaoua Region, and within the campus of the University of Ngaoundéré. This Region belongs to the High Guinean Savannah agroecological zone [15]. The climate is Sudano-Guinean, mild and cool, characterized by two seasons: a rainy season extending from April to October, and a dry season running from November to March [16]. The experimental field was centered at a point with the following geographical coordinates: latitude; 7°26'10.76"N; longitude; 13°33'13.08"E; altitude; 1080 m above sea level. Plant material consisted of *P. vulgaris* seeds purchased from the AGRISEP SARL store located at Carrefour Borongo, while *A. mellifera* colonies and insects were naturally present at the study site.

2.2. Preparation of the Experimental Field, Sowing and Crop Maintenance

The experiment was set up in a complete randomized block design with 9 treatments and 3 repetitions. The experimental field of 92 m² plot was delimited, cleared, ploughed and divided into nine subplots, each measuring 3.5 m long and 2 m wide, separated 0.5 m from each other. *P. vulgaris* seeds were sown in each subplot (subplots receiving termite mound soil, subplots receiving neither termite mound soil nor chemical fertilizer and subplots receiving chemical fertilizer) in eight rows of five holes, for a density of 40 plantlets per sub-plot, spaced 40 cm each other and 40 cm between rows. From germination to the first flowering, the field was regularly weeded with a hoe. During the flowering period, weeding was manual, during which 60 cm high sticks were used to support plants.

2.3. Evaluation of the Impact of Termite Mound Soil on the Germination Rate of *Phaseolus vulgaris*

The number of germinated seeds in the two treatments TT (Termite Mound Soil) and TN (Negative Control) was counted, then the germination rate (Tg) for each treatment was calculated using the formula: $Tg = (N_{gg} / N_{gs}) * 100$, where N_{gg} and N_{gs} represent the number of seeds germinated and the number of seeds sown respectively [17].

2.4. Assessment of the Influence of Termite Mound Soil on Nodulation and Biomass of *Phaseolus vulgaris*

For each subplots untreated termite mound soil nor chemical fertilizer (treatment a), subplots applied with

termite mound soil (treatment b), and subplot applied with fertilizer-NPK (treatment c), 6 plants were labelled. At 35 days after planting (DAP), root nodules were harvested per plant, counted, sun dried, and weighed. Plants were dried in an oven at 72°C for 12 hours and weighed [17]. Plant biomass and nodulation were evaluated on the same 18 individual plants of treatments a, b and c.

2.5. Assessment of Growth Parameters [18]

During the vegetative phase, growth parameters (number of leaves and branches per plant) were assessed at regular weekly intervals by simple counting for the different treatments. Subsequently, plant size was assessed by measuring the height of the plants from the ground to the highest apex using a tape measure. Finally, the diameter at the collar was measured at the point where the stem meets the ground using precision callipers with an accuracy of 0.01 mm.

2.6. Determination of *Phaseolus vulgaris* Reproduction Mode

As soon as the first flower buds appeared, 240 buds were tagged on *Phaseolus vulgaris* plants, with 40 buds per plot on two treatments:

- treatment 1: 120 tagged flower buds left to free pollination, with no capture of insects (Figure 1);
- treatment 2: 120 flower buds tagged and protected from insects (Figure 3), using 1 mm² mesh gauze bags [6].

At harvest, the number of pods formed was counted in both treatments. For each treatment, the fruiting index (*Ifr*) was calculated using the following formula:

$Ifr = (Fb / Fa)$ where *Fb* is the number of pods formed and *Fa* the number of viable flowers initially borne [19].

The difference between the fruiting indices of the two treatments was used to calculate the rates of allogamy (*TC*) and autogamy (*TA*), according to the following formula [20]:

$TC = \{(IfrX - IfrY) / IfrX\} * 100$, where *IfrX* and *IfrY* are the average fruiting indices in the treatment with flowers left open to pollination (*X*) and in the treatment with flowers protected from insects (*Y*) respectively; $TA = [100 - TC]$.



Figure 1. *Phaseolus vulgaris* flower labelled and unprotected at Dang in 2022



Figure 2. Labeled and protected *Phaseolus vulgaris* flower with gauze bag at Dang in 2022

2.7. Determination of the Position of *Apis mellifera* in the Floricultural Entomofauna of *Phaseolus vulgaris*

Observations were made every day for a month on flowers of treatment 1, throughout the flowering periods extending from 6-7h, 8-9h, 10-11h, 12-13h, 14-15h and 16-17h. For each of these time slots, the different insects encountered on flowers at full bloom were identified and counted. As insects were not marked, the cumulative results were expressed by the number of visits [21]. Data obtained were used to determine the frequency of *Apis mellifera* (F_x) in the floristic entomofauna of *Phaseolus vulgaris*, as follows: $F_i = (V_i / V_t) * 100$, where V_i is the number of visits by *Apis mellifera* to the flowers in treatment 1 and V_t is the number of visits by all insects on the same flowers [6].

2.8. Study of the Activity of *Apis mellifera* on *Phaseolus vulgaris* Flowers

Data on the relative frequency of *Apis mellifera* visits on the remaining flowers from treatment 1 were used. Floral products (nectar and/or pollen) collected by *A. mellifera* were recorded during the same dates and time slots as for visit frequency. The Abundance visits per flower was recorded following direct counts. For abundance per 1000 flowers (A_{1000}), foragers were counted on a known number of flowers. A_{1000} was calculated using the formula: $A_{1000} = [(A_x / F_x) * 1000]$, where F_x and A_x are respectively the number of open flowers and the number of foragers actually counted on the open flowers of treatment 1 at time x [6]. Data were recorded on the same date as the frequency of visits. The duration of visits per flower was referred to as the time taken by the bee to collect a floral product (pollen and/or nectar) from a flower [6].

The foraging speed according to [22] was expressed as the number of flowers visited per subsequent minute, using the formula: $V_b = (F_i / d_i) * 60$, where d_i is the duration given by the stopwatch (in seconds) and F_i is the

number of flowers corresponding to d_i [6]. The foraging speed data were recorded at the same daily dates and times as for visit durations, with at least five values per hour, depending on the frequency of *Apis mellifera* activity.

Temperature and hygrometry of the study site were recorded every 30 minutes, from 6 a.m. to 6 p.m., using a portable thermo-hygrometer (techno Line WS 9119) installed in the shade⁶, throughout the observation period.

2.9. Determination of the Impact of Floral Insects, Including *Apis mellifera*, on *Phaseolus vulgaris* Yields

When treatments 1 and 2 were set up, 300 flower buds were tagged and two treatments set up:

- treatment 3: 200 flowers at bud stage, labelled and protected then uncovered, each to be visited by *Apis mellifera* before being protected again.
- treatment 4: 100 flowers at bud stage, labelled and protected, then uncovered and protected again, with no visits from insects or other organisms.

At maturity, pods in treatments 3 and 4 were harvested and counted.

The fruiting rate due to floricultural insects (Fri) was expressed as: $Fri = \{[(F_1 - F_4) / (F_1 + F_2 - F_4)] * 100\}$, where F_1 , F_2 and F_4 are the fruiting rates in treatments 1 (flowers left to pollinate freely), 2 (flowers protected from insects) and 4 (flowers protected, uncovered and then protected again, without visits from insects or any other organism) respectively [23]. For treatment x , the fruiting rate (F_x) was: $F_x = [(number\ of\ fruits\ formed / number\ of\ viable\ flowers\ initially\ borne) * 100]$ [19].

2.10. Description of the Pollination Efficiency of an *Apis mellifera* Visit on *Phaseolus vulgaris*

The fruiting rate was calculated for each treatment. The number of seeds per pod was counted and the percentage of normal seeds was calculated in each treatment. The fruiting rate attributed to *Apis mellifera* (FrA) was determined as: $FrA = \{[(F_3 - F_4) / F_3] * 100\}$, with F_3 the fruiting rate in treatment 3 (flowers protected then uncovered, visited by *Apis mellifera* and protected again) and F_4 the fruiting rate in treatment 4 (flowers protected then uncovered, not visited and protected again) [23].

2.11. Determination of the Cumulative Effect of Termite Mound Soils-*Apis mellifera* on *Phaseolus vulgaris* Yields

This parameter was based on the effect of both termite mound soils and workers of *Apis mellifera* on *P. vulgaris* yield. The comparison of productivity (fruiting rate, mean number of seeds per pod and percentage of normal seeds) were assessed between treatment 3 of the TT subplots (flowers protected then uncovered, visited by *Apis mellifera* and protected again) with those from treatment 4 (flowers protected then uncovered, not visited and protected again).

2.12. Data Processing and Analysis

Data analysis was carried out using descriptive statistics (calculation of means, standard deviations and percentages). The student's t-test to compare means of two samples, the Chi-square (χ^2) test to compare percentages, whereas the Pearson's correlation coefficient (r) was used to study linear relationships between two variables. We also used ANOVA (F) to compare means of more than two samples and Excel 2016 software were applied for these analyses.

3. Results

3.1. Influence of Termite Mound Soil on the Germination of *Phaseolus vulgaris*

The average germination rate of *Phaseolus vulgaris* was significantly ($P < 0.01$) elevated (92.5 %) when seeds were amended with termite mound soil at sowing, compared to 85.83% without seed amendment.

3.2. Variation of *Phaseolus vulgaris* Plant Size Between Treatments with Time

At 42 days after planting, *P. vulgaris* plants ranged in height from 6 to 50.5 cm (Table 1). Analysis of variance showed highly significant differences between treatments ($P < 0.001$). The TP treatment had the highest mean size (41.73 cm), followed by TT (40.48 cm), while the lowest mean size was observed in the treatment TN (34.53 cm). From 14 to 28 days of age, analysis of variance shows no difference between our treatments (TT, TN, TP). Between 35 to 42 days after sowing, the analysis of variances shows very highly significant differences ($P < 0.001$) between TT, TN and TP.

3.3. Effect of Different Treatments on the Number of Leaves of *Phaseolus vulgaris*

From Table 2, between 14 to 21 days, TT had the highest number of leaves (4.07), followed by TP (3.93) and TN (3.9). In contrast at 42 days after sowing the highest number of leaves was recorded in treatment TP (13.53) compared to that of treatments TT (12.3) and TN (11.43).

Table 1. Variation of *Phaseolus vulgaris* plant size depending on time and different treatments at Dang

Traitements	Days after sowing				
	14	21	28	35	42
TT	9.6±1.77 ^a	17.21±1.88 ^a	21.1±3.46 ^a	30.5±6.21 ^b	40.48±4.73 ^a
TN	8.83±1.34 ^a	16.43±2.52 ^a	19.67±3.84 ^a	29.23±4.02 ^b	34.53±4.73 ^b
TP	8.96±1.47 ^a	16.36±1.93 ^a	20.5±3.53 ^a	34.2±5.47 ^a	41.73±4.56 ^a
P	0.12	0.23	0.3	< 0.001	< 0.001

Different letters in the column indicate significant differences at the 5% threshold between treatments for the same parameter. TT=Termite land, TN=Negative control, TP=Positive control, P= Probability.

Table 2. Changes in *Phaseolus vulgaris* leaf count during vegetative growth

Treatments	Days after sowing				
	14	21	28	35	42
TT	2.47±0.50 ^a	4.07±0.36 ^a	6.03±1.32 ^a	10.3±2.61 ^b	12.3±2.61 ^b
TN	2.47±0.50 ^a	3.9±0.40 ^a	5.9±0.95 ^a	9.43±1.75 ^b	11.43±1.75 ^b
TP	2.47±0.50 ^a	3.93±0.36 ^a	6.4±1.003 ^a	11.53±2.5 ^a	13.53±2.51 ^a
P-value	1	0.2	0.2	0.003	0.003

Different letters in the column indicate significant differences at the 5 % threshold between treatments for the same parameter. TT = Termite ground; TN = Negative control, TP = Positive control.

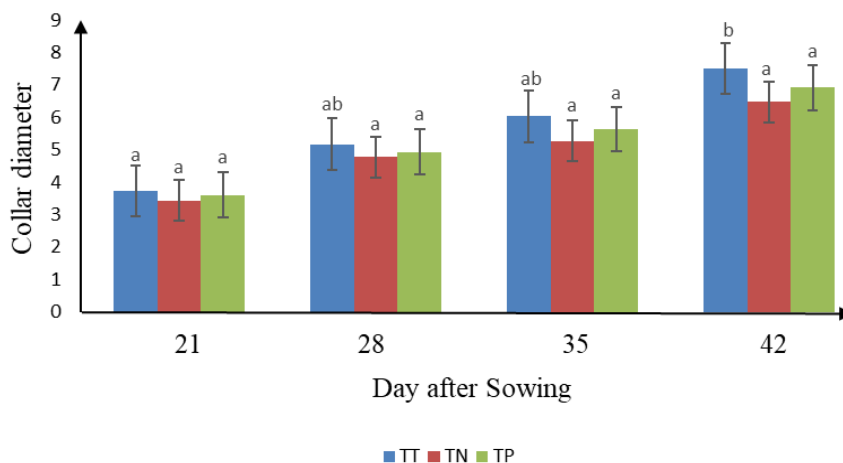


Figure 3. Diameter of *Phaseolus vulgaris* collars as a function of time and treatments at Dang

3.4. Effect of Different Treatments on Collar Diameter of *Phaseolus vulgaris* Plants as a Function of Time

Figure 3 displays variations in *Phaseolus vulgaris* plant collar diameter as a function of treatments and time. At 28 and 35 days after sowing, analysis of variance shows a significant effect ($P < 0.05$) of termite mound soil on the collar diameter of green beans. The difference was highly significant ($P < 0.001$) between treatments for this parameter 42 days after sowing. The highest value was for TT (7.5 mm), while the lowest accounted for TN (6.47 mm) and TP (6.92 mm).

3.5. Effect of Different Treatments on Leaf Area

Table 3 shows the variation in leaf area of *Phaseolus vulgaris* according to the treatments. It shows that the positive control had the highest leaf area with 47.19 cm², followed by TT (41.19 cm²). The lowest value observed was that of the negative control at 39.59 cm². Analysis of variance shows that there is a significant difference ($P < 0.05$) between the green bean treatments on the parameter studied.

Table 3. Variation in leaf area of *Phaseolus vulgaris* according to treatments at Dang

Treatments	Length	Width	Leaf area
TT	9.98±1.75 ^b	6.14±1.06 ^b	41.89±14.56 ^{ab}
TN	9.71±1.60 ^b	5.98±0.99 ^b	39.59±12.20 ^b
TP	11.90±2.43 ^a	6.57±2.61 ^a	47.19±17.07 ^a
P	< 0.001	< 0.001	0.04

Different letters in the column indicate significant differences at the 5% threshold between treatments for the same parameter. TT=Termite land, TN=Negative control, TP=Positive control, P= Probability.

3.6. Influence of Termite Mound Soil on the Number of Flowers, Nodulation and Biomass of *Phaseolus vulgaris*

Plants treated with termite mound soil at sowing produced a significantly greater number of nodules, nodule dry weight and plant biomass compared to untreated plants (Table 4).

Table 4. Number of nodules and plant biomass of *Phaseolus vulgaris* as affected by termite mound soil

Treatments	Number of nodules per/plant	Weight of dry nodules (g/plant)	Plant biomass (g/plant)
TT	34.83±6.46 ^a	0.36±0.12 ^a	13.83±2.04 ^a
TN	12.66±2.16 ^b	0.7±0.17 ^b	4.50±2.34 ^c
TP	20.16±4.99 ^c	0.16±0.08 ^c	7.33±2.25 ^b
P	0.0022	< 0.001	< 0.001

Different letters in the column indicate significant differences at the 5% threshold between treatments for the same parameter. TT=Termite land, TN=Negative control, TP=Positive control, P= Probability.

3.7. Reproduction Mode of *Phaseolus vulgaris*

The fruiting index was 0.87 and 0.7 for treatments 1 and 2 respectively. The allogamy rate was TC= 19.05%

and the autogamy rate TA= 80.95%. Consequently, the studied *P. vulgaris* variety had a mixed allogamous-self-pollinating mode of reproduction, with autogamy predominating over allogamy.

3.8. Place of *Apis mellifera* in *Phaseolus vulgaris* Floral Entomofauna

In 2022, 401 visits of 7 insect species were recorded on *P. vulgaris* flowers. Table 5 lists these insects with their numbers and percentages of visits. From this table, *Apis mellifera* ranks third with 14.21% of visits, after *Xylocopa olivacea* and *Chalicodoma cincta*.

Table 5. List of insects recorded on *Phaseolus vulgaris* flowers at Dang, and number and percentage of visits by the various insects

Insects			n	P (%)
Order	Family	Genus and species		
Hymenoptera	Apidae	<i>Apis mellifera</i> (ne)	57	14,21
		<i>Amegilla</i> sp. (ne)	2	0,49
		<i>Ceratina</i> sp (po)	4	0,99
	Megachilidae	<i>Xylocopa olivacea</i> (ne)	236	58,85
		<i>Chalicodoma cincta</i> (ne)	73	18,2
		Total Hymenoptera	372	92,76
Lepidoptera	Hesperiidae	(1 sp.) (ne)	28	6,98
Coleoptera	Coccinellidae	(1sp.) (cf)	1	0,24
Total			401	100

n: number of visits to 120 flowers over 6 days in 2022; p: percentage of visits = (n / 401) * 100; sp.: species not determined; ne: nectar harvest; po: pollen harvest; cf: flower consumer.

3.9. Activity of *Apis Mellifera* on *Phaseolus Vulgaris* Flowers

3.9.1. Floral Products Harvested

From our field observations, *Apis mellifera* were found to intensively and regularly collect only nectar on flowers from *P. vulgaris* (Figure 4). In contrast, no pollen collection was observed.



Figure 4. *Apis mellifera* collecting nectar in a *Phaseolus vulgaris* flower

3.9.2. Rhythm of Visits According to Daily Time Frames

Figure 5 shows that *Apis mellifera* visited *Phaseolus*

vulgaris flowers from 8 a.m. to 1 p.m., with peak activity between 10 and 11 a.m. Between 6:00 am and 7:00 am, no insect visits were recorded. During this period, the average relative humidity was 68.7 %, with an average ambient temperature of 27.07°C.

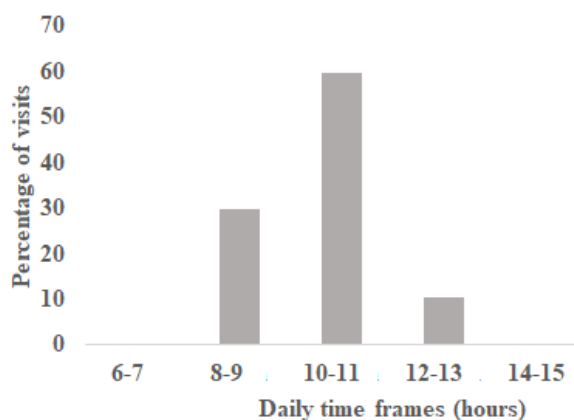


Figure 5. Variation in the frequency of *Apis mellifera* visits to *Phaseolus vulgaris* flowers between daily observation periods at Dang

3.10. *Apis mellifera* Visitation Frequency in Relation to *Phaseolus vulgaris* Flower Blossoming rate

Figure 6 shows the variation in the number of *P. vulgaris* flowers in bloom and the number of *A. mellifera* visits according to observation dates. Analysis of the data reveals that the correlation between these two parameters is positive and significant ($r = 0.89$; $df = 1$; $P < 0.05$).

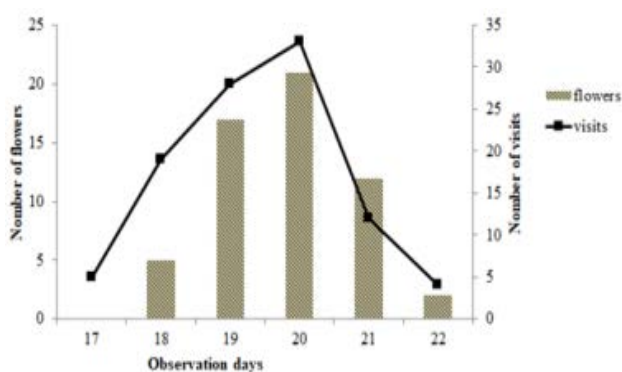


Figure 6. Variation in the number of opened *Phaseolus vulgaris* flowers and the number of *Apis mellifera* visits to these organs between daily observations days at Dang

3.10.1. Abundance of Foragers

The highest number of *Apis mellifera* workers simultaneously active on a *Phaseolus vulgaris* flower was 1. The mean abundance per 1000 flowers was 68 individuals ($n = 15$; $s = 47.07$; $mini = 28.57$; $maxi = 105.26$).

3.10.2. Foraging Speed and Visit Duration Per Flower

The average foraging speed of *Apis mellifera* on *Phaseolus vulgaris* flowers was 9.88 flowers/minute ($n = 15$; $s = 6.8$), while the average time spent visiting each flower to collect nectar was 7.49 seconds ($n = 57$; $s = 7.07$; $min = 3$; $max = 11$).

3.11. Influence of Fauna

Apis mellifera's visits were interrupted by *Xylocopa olivacea* and other insects of the same species (*A. mellifera*) as competitors for nectar. Consequently, *A. mellifera* and *Xylocopa* stopped two (3.50%) and one (1.75%) of the 57 *Apis mellifera* visits respectively.

3.12. Influence of Surrounding Flora

During the *Phaseolus vulgaris* flowering period, flowers of several other plant species in the vicinity of the experimental site were visited by *Apis mellifera* for nectar and/or pollen. During our observations, we did not notice any passage of *Apis mellifera* from the flowers of the plant under investigation to those of other nearby plant species, and vice versa.

3.13. Beekeeping Value of *Phaseolus vulgaris*

During the flowering period of *Phaseolus vulgaris*, we noted a very remarkable activity of *Apis mellifera* workers on its flowers. Specifically, there was a high frequency of visits accompanied by a good nectar harvest and a high degree of fidelity to the flowers. This highlights the great attractiveness of *Phaseolus vulgaris* var marron nectar to *A. mellifera*. These data enable us to classify *Phaseolus vulgaris* var marron as a highly nectar-producing bee plant.

3.14. Impact of *Apis mellifera* on Pollination and Yields of *Phaseolus vulgaris*

workers of *Apis mellifera* were in constant contact with stigmas and anthers throughout nectar gathering (100%). This bee increased *Phaseolus vulgaris*'s potential for pollination in this manner. The percentage of normal seeds, average number of seeds per pod, and fruiting rate for each treatment are displayed in Table 4.

-Fruiting rates were 87.5%, 70.83%, 87.09% and 74% in treatments 1, 2, 3 and 4 respectively. The differences between these four percentages are significant overall ($\chi^2 = 14.054$; $df = 3$; $P < 0.05$). Pairwise comparisons of these percentages show that the difference is very highly significant between treatments 1 and 2 ($\chi^2 = 10.10$; $df = 1$; $P < 0.001$), highly significant between treatments 1 and 4 ($\chi^2 = 9.28$; $df = 1$; $P < 0.01$) and not significant between treatments 1 and 3 ($\chi^2 = 0.004$; $df = 1$; $P > 0.05$), 2 and 3 ($\chi^2 = 3.40$; $df = 1$; $P > 0.05$), 2 and 4 ($\chi^2 = 0.01$; $df = 1$; $P > 0.05$), 3 and 4 ($\chi^2 = 3.25$; $df = 1$; $P > 0.05$).

-Mean numbers of seeds per pod were 4.8, 4.71, 5.14 and 4.39 in treatments 1, 2, 3 and 4 respectively. The differences between these four averages are globally non-significant ($F = 3.06$ ($df_1 = 3$, $df_2 = 290$); $P > 0.05$). Two-way comparisons of these means showed that the difference is highly significant, between treatments 1 and 3 ($t = 1.38$; $df = 113$; $P < 0.01$), significant between 3 and 4 ($t = 2.94$; $df = 99$; $P < 0.05$) and non-significant between treatments 1 and 2 ($t = 0.76$; $df = 191$; $P > 0.05$), 2 and 4 ($t = 1.36$; $df = 160$; $P > 0.05$).

-The percentages of normal seeds were 88.11%, 71.07%, 96.4% and 69.23% in treatments 1, 2, 3 and 4 respectively. The differences between these four percentages are overall very highly significant (overall χ^2

= 85.85; $df = 3$; $P < 0.001$). Pairwise comparisons show that the difference is very highly significant between treatments 1 and 2 ($\chi^2 = 41.49$; $df = 1$; $P < 0.001$), 1 and 4 ($\chi^2 = 45.33$; $df = 1$; $P < 0.001$), 2 and 3 ($\chi^2 = 38.09$; $df = 1$; $P < 0.001$), 3 and 4 ($\chi^2 = 41.05$; $df = 1$; $P < 0.001$), the difference is significant between 1 and 3 ($\chi^2 = 8.24$; $df = 1$; $P < 0.05$) and not significant in treatments 2 and 4 ($\chi^2 = 0.29$; $df = 1$; $P > 0.05$).

3.15. Pollination Efficiency of an *Apis mellifera* Visit on *Phaseolus vulgaris*

The fruiting rate, average number of seeds per pod and percentage of normal seeds due to the influence of an *A. mellifera* visit were 15.03%, 14.59% and 28.18% respectively between treatments T3 and T4.

3.16. Cumulative Effect of Termite Mound Soil-*Apis mellifera* on *Phaseolus vulgaris* Yields

The percentage of normal seeds, average number of seeds per pod, and fruiting rate in treatments PTTFva and PTNFpdnv are shown in Table 7. It shows that:

- fruiting rates were 95% in the PTTFva treatment and 74% in the PTNFpdnv treatment. The difference between these percentages was highly significant ($\chi^2 = 16.84$; $df = 1$; $P < 0.01$);

- PTTFva and PTNFpdnv had an average of 5.81 and 4.39 seeds per pod, respectively. This difference between the two averages was highly significant ($F = 10.91$; $df_1 = 1$; $df_2 = 155$; $P < 0.01$);

- the percentage of normal seeds was 82.95% in the PTTFva treatment and 69.23% in the PTNFpdnv treatment. The difference between these two percentages was highly significant ($\chi^2 = 5.17$; $df = 1$; $P < 0.01$).

As a result, the cumulative effect of termite mound soil and *Apis mellifera* activity was responsible for 22.10% of the fruiting rate, 24.44% of the mean number of seeds per pod and 16.54% of the percentage of normal seeds.

Table 6. Fruiting rate, average number of seeds per pod and percentage of normal seeds according to different treatments at Dang

Traitements	NFE	NGF	TF (%)	Seeds/ pods		NTG	NGN	% GN
				m	s			
T1 (Fl)	120	105	87.5	4.80	1.22	505	445	88.11
T2 (Fpi)	120	85	70.83	4.71	1.30	401	285	71.07
T3 (Fva)	31	27	87.09	5.14	0.66	139	134	96.4
T4 (Fpdnv)	100	74	74	4.39	1.26	325	225	69.23

T: treatment; Fl: flowers left to pollinate freely; Fpi: flowers protected from insects; Fpdnv: flowers protected, then uncovered and protected again, with no visit from insects or any other organism; Fva: flowers protected and visited by *Apis mellifera*; NFE: number of flowers studied; NGF: number of pods formed; NGN: number of normal seeds; NTG: total number of seeds; TF: fruiting rate; % GN: percentage of normal seeds.

Table 7. Yield parameters of *Phaseolus vulgaris* brown seed variety as influenced by *Apis mellifera* and termite mound soil at Dang

Traitements	NFE	NGF	TF (%)	Seeds / pods		NTG	NGN	% GN
				m	s			
T4 (PTNFpdnv)	100	74	74	4.39	1.26	325	225	69.23
T5 (PTTFva)	160	152	95	5.81	2.20	698	579	82.95

NFE: number of flowers opened; NGF: number of pods formed; TF: fruiting rate; NTG: total number of seeds; NGN: number of normal seeds; % GN: percentage of normal seeds; m: mean; s: standard deviation; PTTFva: flowers protected and visited by *Apis mellifera* on termite mound soil subplots; PTNFpdnv: flowers protected, then uncovered and protected again, with no visit from insects or any other organism.

4. Discussion

4.1. Impact of Termite Mound Soil on *Phaseolus vulgaris* Germination

The good germination obtained on the termite mound soil substrate could be explained by the high organic matter content of the termite mound soil in relation to the inoculated seeds. In fact, organic matter is the basis of soil fertility and plays a role in soil structuring [24], thus promoting good seed germination.

4.2. *Phaseolus vulgaris* Growth Parameters

Good growth was observed in plants treated with termite mound soil. The beneficial effect of termite mound soil on green bean plant size observed in this study is thought to be linked to the combined action of improved soil properties and nutrient mineralization. This result is similar to the work of [4] on *Solanum nigrum* in

Brazzaville (Congo), who reported that termite mound soil improved plant height growth compared with the control. It also has a good impact on leaf number and crown diameter. Similar observations were obtained by [4] on *Solanum nigrum* in Brazzaville (Congo), who reported that termite mound soil increased plant crown diameter compared with the negative control.

4.3. *Apis Mellifera* Activity on *Phaseolus Vulgaris* Flowers

At Dang, *A. mellifera* ranked third among bean-flowering insects. This result differs from those obtained in the same locality by [25] on flowers of the small black seeds variety. In contrast, *A. mellifera* as reported as the main floricultural insect of Sesame in Dang [21]. The floral entomofauna of a plant can vary with time and space [6]. *A. mellifera* preyed intensively and exclusively on nectar. The peak activity of *A. mellifera* between 11 and 12 o'clock in the morning is linked to the period of greatest nectar and/or pollen availability in *P. vulgaris*

flowers. The high abundance per 1000 bean flowers would be linked to the ability of honey bees to recruit a high number of foragers to exploit an interesting food source [6]. The positive and highly significant correlation between the number of visits by *A. mellifera* and the number of opened flowers on *P. vulgaris* highlights the attractiveness of the nectar of this Fabaceae to *A. mellifera* foragers.

The disruption of visits due to fauna resulted in a reduction in the duration of some *A. mellifera* visits to *P. vulgaris* flowers; this forced some foragers to visit several flowers during a foraging trip, in order to obtain their load of pollen or nectar as reported by [26] on *Entada africana*, *Psidium guajava*, *Eucalyptus camaldulensis* and *Trichilia emetica*, [27] on *Croton macrostachyus* in Ngaoundere.

The increase in the number of flowers visited by a worker increases the probability of stigmatic contacts and consequently pollination possibilities. The absence of passage of foragers from *P. vulgaris* flowers to those of other neighboring plant species proves that during a foraging trip, *A. mellifera* workers are faithful to the flowers of the plant species exploited.

In Cameroon, honey bee fidelity has also been reported on the flowers of: *Voacanga africana*, *Callistemon rigidus* [28], *Vitellaria paradoxa* [29] and *Abelmoschus esculentus* [36]. This fidelity is explained by the fact that in honey bees, foragers are generally able to memorize and recognize the shape, color and odor of flowers visited on previous foraging trips [30]. As a highly nectariferous bee plant, *P. vulgaris* can be grown in Cameroon's Adamaoua region to increase honey production and help stabilize *A. mellifera* colonies during the rainy season.

4.4. Impact of *Apis mellifera* on *Phaseolus vulgaris* Pollination and Yields

When collecting nectar or pollen from *P. vulgaris* flowers, *A. mellifera* workers regularly come into contact with the stigma and anthers. They can therefore play a direct role in self-pollination by placing pollen from a flower on its stigma. This is all the more likely as autogamy is predominant in *P. vulgaris*.

The positive and significant contribution of *A. mellifera* to the pod and seed yields of *P. vulgaris* is justified by the action of foragers on the pollination of the visited flowers. The positive and significant impact of *A. mellifera* on grain yields via its pollination efficiency has been demonstrated in Cameroon in *Callistemon rigidus* [28], *Glycine max* [31] and in Brazil in *Brassica napus* [32].

4.5. Cumulative Effect of Termite Mound Soil-*Apis mellifera* on *Phaseolus vulgaris* Yields

For this plant, we have shown that through their cumulative action, termite mound soil and *A. mellifera* increase the fruiting rate, the number of seeds per pod and the number of normal seeds. In fact, the mineral-rich termite mound soil improves the plant's mineral nutrition [24]. As a result, most of their requirements for growth, flowering and increased production were revealed [33] are available. In addition, insects, including *A. mellifera*, as

they move from flower to flower, are thought to have a positive effect on the pollination of several legumes [34], thereby increasing pod and/or seed yields [35,36].

5. Conclusion

The aim of this study was to sustainably contribute to the improved growth potential and yield of the brown *Phaseolus vulgaris* at Dang, located in Ngaoundere-Cameroon. The outcomes got from this study uncoverer that termite mound soil improves *Phaseolus vulgaris* seed germination compared with the negative control. It increased the fruiting rate, number of seeds per pod and percentage of normal seeds by 18.75%, 1.96% and 4.31% respectively. Out of 401 recorded visits, seven different insect species were involved, with *Apis mellifera* coming third in terms of visit frequency at 14.21%. These insects increased fruiting rates, the average number of seeds per pod and the percentage of normal seeds. When *A. mellifera* visited *P. vulgaris*, fruiting rates, average number of seeds per pod and percentage of normal seeds were increased at 15.03%, 14.59% and 28.18% respectively. The combined action of termite mound soil and *A. mellifera* positively affected the fruiting rate, average number of seeds per pod and percentage of normal seeds by 22.10%, 24.44% and 16.54% respectively. The field application of termite mound soil associated to the activity of *A. mellifera* could thus be recommended to sustainably boost the production of *P. vulgaris*.

Conflicts of interest: The authors declare no conflicts of interest.

Authors' Contributions: TA contributed to the literature search and field data collection. KBS, MM and KI contributed to the first draft, data analysis and scientific orientation. AN coordinated all the work.

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