Pollination efficiency of *Apis mellifera* (Hymenoptera: Apidae) on *Jatropha curcas* (Euphorbiaceae) and its impact on yields in Maroua (Cameroon)

KAYAODA TCHABRA Barbara[1], DJONWANGWE Denis[2*], ZRA GANAVA Venceslas[3]
[1]*Department of Biological Sciences, Faculty of Science, University of Maroua, P.O. Box 814 Maroua, Cameroon*
[2]*Department of Life and Earth Sciences, Higher Teachers' Training College, University of Maroua, P. O. Box 55 Maroua, Cameroon*
[3]*Department of Agriculture Livestock and Derived Products, National Advanced School of Engineering, University of Maroua, P.O. Box 58, Maroua, Cameroon*
**E-mail : djonwangwedenis@gmail.com; Tel : (+237) 675658519 ;*
ORCID iD : 0000-0002-5782-2836
Keywords: *Apis mellifera*, *Jatropha curcas*, Maroua, pollination, yields.

Submitted 11/11/2024, Published online on 31st January 2025 in the *Journal of Animal and Plant Sciences (J. Anim. Plant Sci.) ISSN 2071 – 7024*

1 ABSTRACT

***Jatropha curcas* L. 1753 is a plant from the Euphorbiaceae family capable of restoring soil and solving certain health problems. This work was carried out from June to July in 2022 and 2023 to assess the impact of *Apis mellifera* bees on fruit and seed yields of *J. curcas* in Maroua. In 2022, 60 flower bouquets left in free pollination constituting treatment 1; treatment 2, 60 floral bouquets isolated from insect visits; treatment 3, 60 flowers protected and open for a single visit from *A. mellifera*; treatment 4 consisting of 60 flowers isolated from insect visits, discovered and reprotected without visit. In 2023, the 1', 2', 3' and 4' treatments are the repeats of the first four treatments, respectively. The foraging behaviour of this bee, its pollinating efficiency on fruiting rate, the number of seeds per fruit and the percentage of normal seeds were evaluated. The results show that out of 13 insect species recorded on *J. curcas* flowers, *A. mellifera* comes in first place in 2022 and 2023 with 34.74% and 53.10% of visits respectively. This bee collects nectar heavily and pollen weakly. Through its pollinating efficiency, this bee has promoted a significant increase in the fruiting rate by 100%, the percentage of the average number of seeds per capsule by 20.27% and the percentage of normal seeds by 14.68%. The installation of honeybee hive close to *J. curcas* populations is recommended to improve capsule production, seed quality and honey yield.**

2 INTRODUCTION

Nowadays, non-food plant species can be considered as a solution to biodiversity conservation due to their ability to produce biofuels (Tchuenteu *et al.*, 2013; Kabe *et al.,* 2019). *Jatropha curcas* is widely cultivated in Central Africa, South America, India and South Asia mainly to mark land boundaries, fertilization of degraded soils (Central Africa) and the production of high-quality oil (Katembo & Gray, 2007; Maes *et al.*, 2009). In addition to its energy potential, *J. curcas* is used as an insecticide to control various insect pests (Penjit, 2012; Abdoulaye, 2018) and its proven therapeutic virtues against intestinal parasitosis and heart disorders (Anguessin *et al.*, 2021). *Jatropha curcas* is a monoecious plant with male and female flowers on the same plant and on the same inflorescence. The slightly larger female flowers occupy the centre of the inflorescence and have a shorter peduncle than the male flowers. (Raju & Ezradanam, 2002; Chang-wei *et al.*, 2007). Hermaphrodite flowers are sometimes observed and can be self-pollinated (Heller, 1996). However, obtaining of fruit and seeds is linked to the pollination of flowers (Dymond *et al.*, 2021), the effective perpetrators of which are pollinating insects (Mateos-Fierro *et al.*,2022) Given the importance of insects in the pollination of *J. curcas*, the floricultural entomofauna of this plant has been studied in other localities: in Samaru-Zaria in Nigeria, Alamu *et al.* (2013) found that *Apis mellifera* (Apidae), *Chrysomya chloropyga* (Calliphoridae) and *Eristalis tenax* (Syrphidae) are the major pollinators of this plant; in Zambia and Malawi respectively, Negussie *et al.* (2013) found that honey bees *A. mellifera* is the major pollinator of *J. curcas* in these countries; in Thailand, on the flowers of *J. curcas* (Pananya *et al.*, 2015) found that *Eristalis obscuritarsis*, *Eristalis arvorum,* and *Helophilus bengalensis* are the major pollinators of this Euphorbiaceae. In Cameroon, research on pollinating insects is experiencing considerable growth thanks to in-depth investigations carried out for several years, particularly in the Adamawa regions Djonwangwé *et al.*, 2011a, b, c; Djakbé *et al.*, 2017; Mohamadou *et al.*, 2018; the Far North (Azo'o *et al.*, 2011, 2012, 2017; Dounia *et al.*, 2016; Douka *et al.,* 2017; Djonwangwé *et al.*, 2017; the Littoral (Taïmanga & Tchuenguem, 2018) and the North (Basga *et al.*, 2018). Despite these efforts, due to a lack of information, the floricultural entomofauna and its impact on *J. curcas* yields remain unknown in this country, which leads to a lack of interest in this Euphorbiaceae despite its economic, ecological and therapeutic importance. The general objective of this work is to contribute to the knowledge of *J. curcas* pollinators in order to conserve the latter's biodiversity and benefit from the services it provides.

Specific objectives include:

- determine the place of *A. mellifera* in *J. curcas* floral entomofaune;
- study the activity of *A. mellifera* on *J. curcas* flowers;
- assess the impact of the flowering insects including *A. mellifera* on capsule and seed yields of this Euphorbiaceae;
- evaluate the pollination efficiency of *A. mellifera* on *J. curcas.*

3 MATERIALS AND METHODS

3.1 Study site: The study took place from June 26 to July 03 in 2022 and from June 27 to July 06 in 2023 in Maroua (Diamaré Department, Far North Region of Cameroon). The study station was centered at the point of coordinates: 10°36'17.712" N latitude, 14°18'8.849 E longitude and 405 m altitude. The climate is the Sudano-Sahelian type characterized by two seasons: a long dry season (November to May) and a short rainy season (June to October) (Kuete *et al.*, 1993). The choice of this observation site is justified by the existence of several *J. curcas* plants whose flowers are accessible to the observer.

3.2 Biological Material : The plant material was represented by *J. curcas* plants planted by a peasant as a living hedge. The animal material consisted of the insects naturally present in the environment and which visited the flowers of *J. curcas.*

3.3 Methods

3.3.1 Determination of the reproductive system of *Jatropha curcas*: From June to July 2022 and 2023, 240 flower bouquets of *J. curcas* were labelled on 15 plants and 4 treatments consisted of : treatment 1 (239 female flower buds and 1449 males) and 1' (259 female flower buds and 2047 males): 120 flower bouquets labelled and left in free pollination (**Figure 1**) (for the years 2022 and 2023). Treatment 2 (227 female flower buds and 1814 males) and T2' (247 female flower buds and 1852 males): 120 flower bouquets labelled and protected from insects using gauze cloth bags (**Figure 2**) (for the years 2022 and 2023). After five days the flowers wilted, the number of fruits formed in each treatment was counted and the fruiting index was calculated using the following formula (Tchuenguem *et al.*, 2001): $Ifr = F2/F1$ where $F2$ is the number of fruits formed and $F1$ is the number of viable flowers initially borne. For each observation season, the difference between the fruiting indices of the two treatments made it possible to calculate the rates of outcrossing (*TC*) and autogamy (*AF*) in the broad sense, according to the following formulas (Demarly, 1977):

$TC = \{[(Ifr1 - Ifr2) / Ifr1] \times 100\}$ where *Ifr1* and *Ifr2* are respectively the fruiting indices in the free-flowering treatment (treatment 1) and in the protected flowering treatment (treatment 2). $BP = 100 - TC$.

Figure 1: Flower bouquets of *Jatropha curcas* labelled and left open-pollinated in 2023 at Maroua (Missingleo).

Figure 2: Flower bouquets of *Jatropha curcas* labelled and protected with a gauze bag in 2023 at Maroua (Missingleo).

3.3.2 Study of the activity of *Apis mellifera* on *Jatropha curcas* flowers: For each year of investigation, the study of the frequency of visits focused on the flowers of treatment 1. Regarding especially the study of the duration of visits per flower, the speed of foraging and the abundance per 1000 flowers, several male and female flowers were also considered.

3.3.2.1 Floral products collected by *Apis mellifera*: The aim was to note whether the visiting honey bee collected pollen, nectar, or both of them from *J. curcas* flower. An insect that sinks its mouthparts or head deep into the corolla of a flower is a nectar forager; if it scratches the anthers with its mandibles and/or legs, it is a pollen forager (Jacob - Remacle, 1989).

3.3.2.2 Duration of visits of *Apis mellifera*: The duration of pollen collection visits and nectar collection visits were recorded separately, on the same dates as for the frequency of visits, during the following daily time slots: 7 - 8 a.m., 9 - 10 a.m., 11 a.m. - 12 p.m., 1 - 2 p.m., 3 - 4 p.m. and 5 - 6 p.m. The time is set in motion as soon as the bee lands on a flower and stops as soon as the bee leaves. The duration of the visit carried out corresponds to the value read on the stopwatch (Tchuenguem, 2005).

3.3.2.3 .Foraging speed: The foraging speed (number of flowers visited per minute: Jacob-Remacle, 1989) was recorded. The timer was set

to zero as soon as a forager landed on a flower. The number of flowers visited by the flower was then counted, as it passed from flower to flower. The time was stopped as soon as the forager was lost from sight. The foraging speed *(Vb)* is:
$Vb = (Fi / di) * 60$ where *di* is the duration given by the stopwatch (in seconds) and *Fi* is the number of flowers corresponding to *di* (Tchuenguem *et al*., 2004). The number of visits interrupted by competitors or predators during the foraging activity of *A. mellifera* and the attractiveness of the flowers of neighbouring plants were systematically noted when timing the duration of visits by flower. Throughout the observation period, the temperature and humidity of the study station were recorded from 6 a.m. to 6 p.m., every 30 minutes, by a portable thermo-hygrometer placed in the shade (Tchuenguem *et al.,* 2004).

3.3.2.4 Abundance of *Apis mellifera*: The aim here was to count the largest number of workers simultaneously active on a flower and on 1000 flowers during the observation period (Tchuenguem, 2005). Abundances per flower are recorded following direct counts The abundance per 1000 flowers (A_{1000}) is calculated using the following formula: $A_{1000} = [(Ax / Fx) \times 1000]$, where *Fx* and *Ax* are respectively the number of flowers in bloom and the number of foraging insects actually counted on the flowers left in free pollination at time *x* (Tchuenguem, 2005). The data were recorded on the same dates and time slots as for the duration of visits per flower, at a rate of at least five values per time slot, when the activity of that bee allowed it.

3.4 Evaluation of the impact of anthophilous insects including *Apis mellifera* on *Jatropha curcas* yields: It is based on the impact of antophilic insects on pollination; the impact of pollination on fruiting; the comparison of fruit yields (fruiting rate) of the treatment with flowers left in free pollination with those of the treatment with flowers protected from insects (Tchuenguem *et al*., 2001). For each year of study, the fruiting rate (*Pi*) due to the influence of floricultural insects was calculated using the following formula (Tchuenguem *et al*., 2004):
$Pi = [(F1 - F2) / F1] * 100$ where *F1* and *F2* are the fruiting rates in treatments 1 (flowers left in open pollination) and 2 (flowers protected) respectively. The percentage (*Pg*) of the number of seeds per capsule, the percentage (*Pn*) of normal seeds due to the influence of flowering insects were calculated in the same manner as for the fruiting rate.

3.5 Evaluation of the pollination efficiency of *Apis mellifera* on *Jatropha curcas* flowers: In parallel with the implementation of treatments 1 and 1'; 2 and 2', four other treatments were constituted. The 3 and 3' treatments; 4 and 4' each consisting of 60 labelled female flower buds, intended for a single visit of *A. mellifera* or not. For each year of observation, as soon as each flower of the 3 and 3' treatment opened, the gauze cloth was delicately removed during the period of optimal activity of the *A. mellifera* workers and the flowers left in free pollination were observed for 1 to 10 minutes, to note the possible visit by a worker of *A. mellifera*. After this manipulation, the flower was protected again and was no longer handled (Fameni *et al*., 2012). For the 4 and 4' treatments, as soon as each flower opened, the gauze cloth was delicately removed, during the daily period of optimal insect activity and the flower left in free pollination was observed for 10 minutes and then closed without the visit of insects or any other organisms. For each year of study, the direct numerical contribution (*Frx*) of *A. mellifera* to fruiting was calculated according to the formula: $Frx = [(FrZ - FrY) / FrZ] * 100$ (Tchuenguem *et al*., 2001), where *FrZ* and *FrY* are the fruiting rates in the *Z* treatments (flowers protected and exclusively visited by *A. mellifera*) and *Y* (protected and unvisited flowers). At maturity, the capsules from each of the 3, 3', 4 and 4' treatments were harvested and the number of seeds counted. The fruiting rate, the percentage of seeds per capsule and the percentage of normal seeds attributable to *A. mellifera* were calculated in the same manner as those attributable to floricultural insects.

3.6 Data analysis: The data analysis was done using:

- descriptive statistics (calculation of averages, deviations - types and percentages);
- four tests: (a) Student's t-test for the comparison of the means of two samples; (b) chi-square (χ^2) for percentage comparison; (c) Pearson correlation coefficient (r) for the study of linear relationships between two variables; (d) ANOVA (F) for the comparison of the means of more than two samples.
- Excel 2013 spreadsheet and SPSS.20 software were used.

4 RESULTS

4.1 Reproduction mode of *Jatropha curcas*: In 2022, the fruiting index was 0.92 (n = 220; s = 2.82) and 0.18 (n = 42; s = 1.27) for T1 and T2 treatments, respectively; in 2023, the corresponding figures were 0.87 (n = 226; s = 2.26) and 0.12 (n = 30; s = 0.42) for T1' and T2' treatments. Thus, in 2022, TC = 80.43% and TA = 19.57%; while in 2023, TC = 86.20% and TA = 13.8%. For the two years of study combined, TC = 83.31% and TA = 16.68%. Consequently, *J. curcas* has a mixed mating mode, allogamous and autogamous, with the predominance of allogamy.

4.2 Diversity and frequency of the flowering entomofauna of *Jatropha curcas*: In 2022 and 2023 respectively, 570 and 1900 visits of 6 and 7 species of insects belonging to 6 families and 3 orders were counted on 1688 and 2306 male and female flowers of *J. curcas* left in free pollination constituting treatment 1. Table 1 presents the list of insects recorded on flowers left in free pollination with their frequency of visits. It appears from this table that overall, the insect most present on the flowers of *J. curcas* was *A. mellifera* with a relative frequency of 34.74% in 2022 and 53.11 in 2023.

Table 1: Diversity of flowering insects on *Jatropha curcas* in 2022 and 2023 at Missingleo, number and percentage of visits of different insects.

	Insects		**2022**		**2023**		**Total** 2022/2023	
Order	**Family**	**Genus and species**	n_1	p_1 (%)	n_2	p_2 (%)	n_T	p_T (%)
Hymenoptera	Apidae	*Apis mellifera*	198	34.74	1009	53.11	1207	43.93
	Vespidae	*Rhynchium marginellum*	20	3.51	30	1.58	50	2.55
	Vespidae	*Belonogaster juncea*	32	5.61	303	15.95	335	10.79
Diptera	Calliphoridae	*Chrysomya chloropyga*	140	24.56	328	17.26	469	20.91
		Chrysomya megacephala	169	29.56	10	0.53	179	15.05
	Syrphidae	*Eristalinus fuscicornis*	11	1.93	-	-	11	0.97
Lepidoptera	Pieridae	*Catopsilia florella*	-	-	200	10.53	200	5.27
		Rhyncomya pruinosa	-	-	20	1.05	20	0.53
Total: 3 orders	**6 families**	**8 species**	**570**	**100**	**1900**	**100**	**2470**	**100**

n_1: number of visits to 1688 flowers in 2022; n_2: number of visits to 2306 flowers in 2023; p_1 percentage of visits in 2022 ($p_1 = (n_1 / 570) \times 100$); p_2: percentage of visits in 2023 ($p_2 = (n_2 / 1900) \times 100$); p_T = average percentage of visits during the two years of observation $(p_1+p_2)/2$; n_T = total number of visits (n_1+n_2);

4.3. Study of the activity of *Apis mellifera* on *Jatropha curcas* flowers

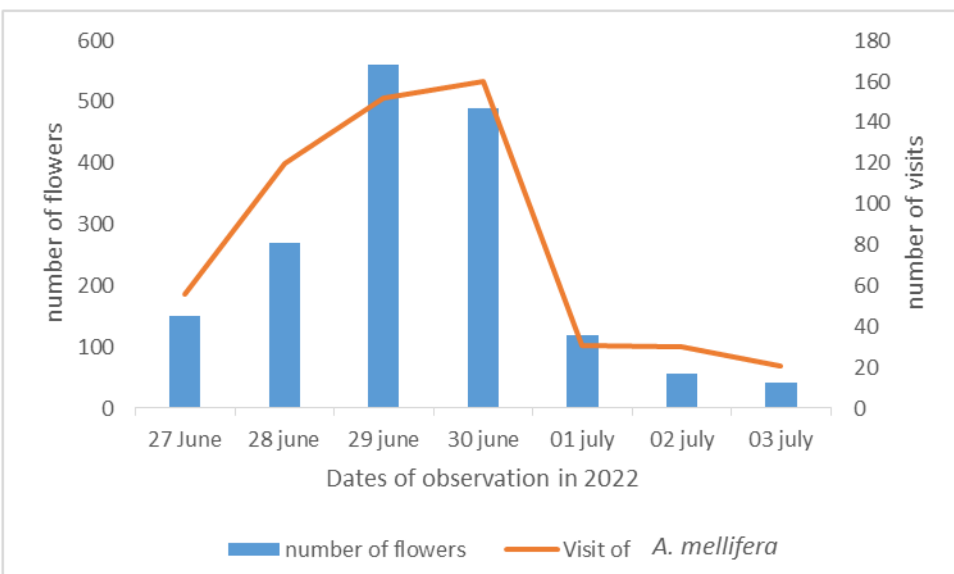
4.3.1. Floral products collected by *Apis mellifera*: This bee collected nectar (Figure 3) and pollen (Figure 4) from the flowers of *J. curcas*. In 2022, out of 272 timed visits to the flowers, 255 (or 93.75%) were devoted to nectar harvesting and 17 (or 6.25%) to pollen sampling. For the year 2023, out of 204 visits, the corresponding values were 174 (or 85.29%) for nectar and 30 (or 14.70%) for pollen.

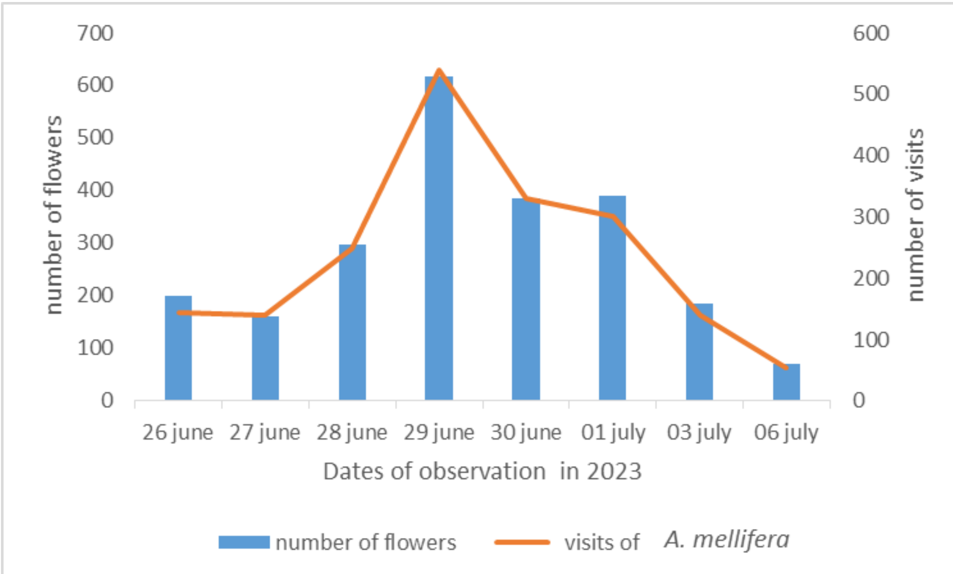
Figure 3: *Apis mellifera* collecting nectar on *Jatropha curcas* flower at Maroua (Missingleo) in 2023.

Figure 4: *Apis mellifera* collecting pollen on *Jatropha curcas* flower at Maroua (Missingleo) in 2023.

4.3.2 Rhythm of visits according to the flowering stages: Overall, bee visits were higher in the *J. curcas field* when the number of blooming flowers was higher (Figure 5). The correlation between the number of blooming flowers and the number of visits to *A. mellifera* is positive and very highly significant in 2022 (r = 0.96; df = 6; P < 0.001) and in 2023 (r = 0.99; df = 7; P < 0.001).

A



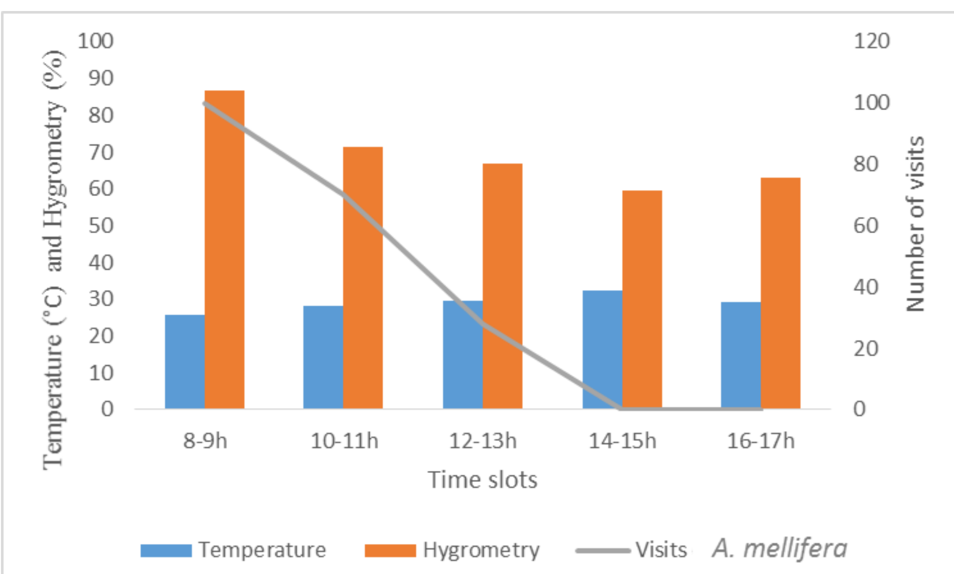


B

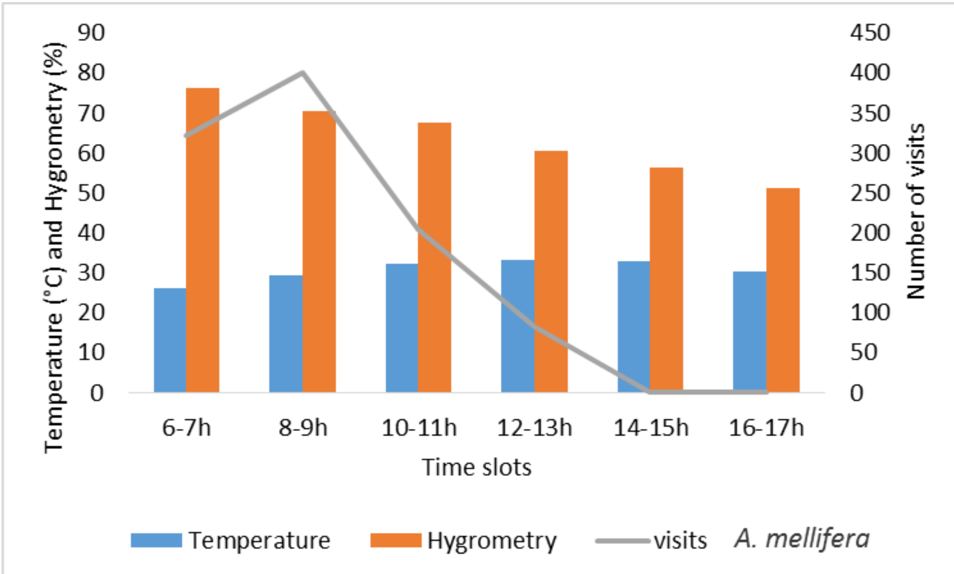
Figure 5: Seasonal variation of the number of *Jatropha curcas* opened flowers of blooming flowers and the number of *Apis mellifera* visits on these organs, in 2022 (A) and 2023 (B) at Missingleo.

4.3.3 Daily rhythm of visits: *Apis mellifera* was active on *J. curcas* flowers from 8 a.m. to 3 p.m. in 2022 and 6 a.m. to 5 p.m. in 2023, and throughout its blooming period, with a peak of visits between 8 and 9 a.m. in 2022 as well as in 2023 (Figure 6). This figure shows that:

- in 2022, the correlation was significant between the number of *A. mellifera* visits and the temperature ($r = 0.87$; $ddl = 4$; $P < 0.05$), while it was highly significant between the number of visits and the relative humidity ($r = 0.95$; $ddl = 4$; $P < 0{,}01$);
- in 2023, the correlation was not significant between the number of *A. mellifera* visits and the temperature ($r = 0.62$; $df = 5$; $P > 0.05$), while it was highly significant between the number of visits and the relative humidity ($r = 0.91$; $ddl = 5$; $P < 0{,}01$).



A



B

Figure 6: Daily variation of *Apis mellifera* visits on *Jatropha curcas* flowers in 2022 (A) and 2023 (B) at Missingleo, mean temperature and mean humidity of the study station.

4.3.4 Abundance of *Apis mellifera*: The largest number of individuals simultaneously active on a *J. curcas* flower was one for both years of observations.During the 15 days of observations, in no case were more than one individual per flower observed. In 2022 and 2023, the mean abundance of *A. mellifera* per 1000 flowers was 33.87 (n = 121; s = 27.91) and 17.12 (n = 165; s = 12.78) respectively. The difference between these two means abundances per 1000 flowers is very highly significant (t = 6.80; df = 284; $P < 0.001$).

4.3.5 Duration of visits per flower: The mean nectar harvest time by *A. mellifera* was 3.37 sec (n = 255; s = 1.70) and 3.11 sec (n = 17; s = 1.1) for pollen collection in 2022. The difference between the mean duration of a nectar collection visit and the average duration of a pollen collection visit is not significant (t = 0.59; df = 270; $P > 0.05$). In 2023, the mean nectar harvest time was 2.47 sec (n = 174; s = 0.97) and 1.65 sec (n = 20; s = 0.49) for pollen collection. The difference between the mean duration of a nectar collection visit and the mean duration of a pollen collection visit is very highly significant (t = 3.67; df = 192; $P < 0.001$);

4.3.6 Foraging speed of *Apis mellifera* on *Jatropha curcas* flowers: The mean foraging speed of *A. mellifera* was 8.57 flowers/min (n = 113; s = 3.33) in 2022 and 12.09 flowers/min (n = 163; s = 4.79) in 2023. The difference between these two means foraging speeds is very highly significant (t = 6.74; df = 274; $P < 0.001$).

4.4 Impact of anthophilous insects including *Apis mellifera* on *Jatropha curcas* yields: Table 2 summarizes the fruiting rate, the mean number of seeds per capsule and the percentage of normal seeds in the different treatments of *J. curcas* in 2022 and 2023.

Table 2: Fruiting rate, mean number of seeds per capsule and percentage of normal seeds according to different treatments of *Jatropha curcas* in 2022 and 2023 at Missingleo.

Years	Treatments	NSF	NFC	TR(%)	Seed/capsule		TNS	NNS	%NS
					m	*s*			
2022	T1	239	220	92.05	2.60	0.59	574	543	94.59
	T2	227	42	18.50	1.06	0.38	104	93	89.24
	T3	60	60	100	2.92	0.27	175	175	100
	T4	60	34	56.76	0.94	0.31	82	73	89.02
2023	T1'	259	226	87.25	2.82	0.38	637	636	99.84
	T2'	247	30	12.14	2.77	0.50	83	80	96.38
	T3'	60	60	100	2.92	0.27	175	175	100
	T4'	60	40	57.97	2.78	0.42	111	106	96.38

NSF: number of studies flowers; NFC: number of formed capsule; TR: fruiting rate; TNS: total number of seeds; NNS: number of normal seeds; % NS: percentage of normal seeds; m: mean; s: standard deviation; T1 and T1': unprotected flowers; T2 and T2': protected flowers; T3 and T3': flowers protected unbagged, exclusively visited once by *Apis mellifera* and rebagged; T4 and T4': flowers protected then unbagged and rebagged without visit by insects or any other organism.

It is apparent from this table that:
- fruiting rates were 92.05%, 18.50%, 100%, 56.76%, 87.25%, 12.14%, 100%, and 57.97 in the T1, T1', T2, T2' T3, T3' T4 and T4' treatments respectively. The overall comparison between these percentages is very highly significant (χ^2 = 255.87; *df* = 7; *P* < 0.001). In 2022, the two to two comparison of these percentages shows that the difference is very highly significant between T1 and T2 treatments (χ^2 = 255.87; *df* = 1; *P* < 0.001), T3 and T4 (χ^2 = 33.19; *df* = 1; *P* < 0.001), T1 and T3 (χ^2 = 5.09; *df* = 1; *P* < 0.001) and between T2 and T4 (χ^2 = 35.50; *df* = 1; *P* < 0.001).In 2023, the two to two comparison of these percentages shows that the difference is very highly significant between the T1' and T2' treatments (χ^2 = 285.87; *df* = 1; *P* < 0.001) between T3' and T4' (χ^2 = 24.00; *df* = 1; *P* < 0.001), T1' and T3' (χ^2 = 81.52; *df* = 1; *P* < 0.001) and between T2' and T4' (χ^2 = 8.53; *df* = 1; *P* < 0.001).The mean number of seeds per pod was 2.60, 1.06, 2.92, 0.94, 2.82, 2.77, 2.92 and 2.78 in the T1, T1', T2, T2, T3, T3 and T4' treatments, respectively. The difference between these means is very highly significant (*F* = 78.38; *df* = 6; *P* < 0.001). In 2022, the two to two comparison of these means shows that the difference is very highly significant between T1 and T2 treatments (*t* = 12.69; *df* = 304; *P* < 0.001), T3 and T4 (*t* = 7.10; *df* = 92; *P* < 0.001), T1 and T3 (*t* = 4.62; *df* = 278; *P* < 0.001) and between T2' and T4' (*t* = 5.05; *df* = 118; *P* < 0.001). In 2023, the two to two comparison of these averages shows that the difference is not significant between the T1' and T2' treatments (*t* = 0.66; *df* = 254; *P* > 0.05), between T3' and T4' (*t* = 1.87; *df* = 98; *P* > 0.05), T1' and T3' (*t* = 1.80; *df* = 275; *P* > 0.05) and between T2' and T4' (*t* = 0.75; *df* = 68; *P* > 0.05). The percentages of normal seeds were 94.59%, 89.24%, 100%, 89.02%, 99.84%, 96.38%, 99.84% and 96.38% in the T1, T1', T2, T2 ' T3, T3 ' T4 and T4' treatments respectively. The overall comparison between these percentages is very highly significant (χ^2 = 76.97; *df* = 6; *P* < 0.001). In 2022, the two to two comparison of these percentages shows that the difference is significant between T1 and T2 treatments (χ^2 = 4.06; *df* = 1; *P* < 0.05), very highly significant between T3 and T4 (χ^2 = 19.90; *df* = 1; *P* < 0.001), T1 and T3 (χ^2 = 9.86; *df* = 1; *P* < 0.001) and not significant between T2 and T4 (χ^2 = 0.01; *df* = 1; *P* > 0.05). In 2023, the two to two comparison of these percentages shows that the difference is very highly significant between T1' and T2' treatments (χ^2 = 15.89 ; *df* = 1 ; *P* < 0.001) and T3' and T4' (χ^2 = 8.02 ; *df* = 1 ; *P* < 0.001), not significant between T1' and T3' (χ^2 = 0.28 ; *df* = 1 ; *P* > 0.05) and T2' and T4' (χ^2 = 0.10 ; *df* = 1 ; *P* > 0.05).

4.5 Pollination efficiency of *Apis mellifera* on *Jatropha curcas*: Fruiting rates due to the activity of *A. mellifera* were 100% in

2022 and 2023. The percentages of the average number of seeds per capsule attributable to the impact of *A. mellifera* were 18.85% in 2022, 1.42% in 2023 and 20.27% for the two years of experimentation combined. The percentages of normal seeds attributable to the influence of *A. mellifera* were 8.81% in 2022, 5.87% in 2023 and 14.68% for the two years of experimentation combined.

5 DISCUSSION

5.1 Insect activity on *Jatropha curcas* flowers: In Maroua in the Far North Region of Cameroon, *A. mellifera* is the most predominant insect on the flowers of *J. curcas*. This high frequency of bees is justified by the availability of floral products of this plant and by the ability of the honey bee to recruit a large number of foragers to exploit an interesting food resource (Roubik *et al*., 2005; Abrol, 2012). Alamu *et al*. (2013) in Nigeria found that *A. mellifera* was among the most predominant insects on the flowers of *J. curcas* in the locality of Samaru-Zaria. The floricultural entomofauna of plants in the same family can vary; Reddi & Subba (1983) who found in India that the most common insects on the flowers of *J. gossypiifolia* were *Trigona* sp., *A. florea* and *A. cerana*. *Apis mellifera* collected nectar and pollen from the flowers of *J. curcas* with a peak of activity between 8-9 hours. The peak of activity of this bee on *J. curcas* flowers in the morning would be linked to the greater availability of nectar and/or pollen at the level of the flowers of this plant. These results are contrary to those obtained by Negussie *et al.* **(**2013) in Malawi and Zambia where the peak of insect activity was reached in the 10 a.m**.** to 11 a.m. and 12 p.m. to 1 p.m. time slots. The high abundance of *A. mellifera* per 1000 flowers and the positive and significant correlation between the number of visits to *A. mellifera* and the number of flowers of *J. curcas* highlights the high attractiveness of the nectar and/or pollen of this Euphorbiaceae to this bee. Negussie *et al.* (2013) observations in Malawi and Zambia revealed that *A. mellifera* and *Chrysomya chloropyga* are the most abundant species on the flowers of *J. Curcas*. The very highly significant difference between the mean duration of a nectar and pollen harvest visit is linked to the accessibility of each of these floral products. This is because pollen is produced by the anthers above the nets and, therefore, is easily accessible to the bee. On the other hand, nectar is found in the corollary tube between the base of the style and the stamens, making it less accessible than pollen (Christian *et al*., 2018). The very highly significant difference in the average foraging speeds for the two years could be due to the ability of *A. mellifera* to harvest floral products. The positive and very highly significant contribution of insects in fruiting, the number of seeds per capsule and the percentage of normal seeds highlights the important role that insects play in the process of plant pollination, especially that of *J. curcas*.

5.2 Impact of *Apis mellifera* activity on pollination and yields of *Jatropha curcas*: The fruiting rate was 92.05% for T1, 18.50% for T2, 87.25% for Tl' and 12.14% for T2'. The overall comparison of these four percentages shows a very highly significant difference (χ^2 = 542.66; *df* = 3; *P* < 0.001). The two-to-two comparison of these percentages shows that the difference is very highly significant between the Tl and T2 treatments (χ^2_{2022} = 255.87; *df* = 1; *P* < 0.001), and between the T1' and T2' treatments (χ^2_{2023} = 285.87; *df* = 1; *P* < 0.001). These results would mean that the flowers visited by the insects produce more fruit than those isolated from the visits. The numerical contribution of all insects to the fruiting rate is 65.66% and 70.69% in 2022 and 2023 respectively. According to the work of Negussie *et al*., 2013, insects contribute 77% to fruit formation in Malawi, but the work of Rincón-Rabanales *et al*. (2016), that the increase in fruit production by insects is 86.3% in south-eastern Mexico. The mean number of seeds per capsule was 2.60 for Tl treatment; 1.06 for T2 treatment; 2.82 for T1' treatment and 2.77 for T2' treatment. The overall comparison of the mean number of seeds per capsule of the different treatments shows a very highly significant difference (F = 117.91; df = 6; P < 0.001). The two-to-two comparison of the mean number of seeds per capsule shows a very highly significant difference between the T1 and T2 treatments (t_{2022} = 12.69; df = 304; P < 0.001), and not significant between T1' and T2' (t_{2023} = 0.66; df = 254; P>0.05). The numerical contribution of all insects to the average number of seeds per capsule is 14.18% in 2022 and 1.42% in 2023. These results are contrary to those of Népidé & Tchuenguem, (2016) where insects had an impact on the mean seed number of 27.60% in 2013 and 2.88% in 2014 on the flowers of *Croton macrostachyus* (Euphorbiaceae) at Dang. The percentage of normal seeds was 94.59% for the T1 treatment; 89.24% for the T2 treatment; 99.84% for the T1' treatment; 96.38% for the T2' treatment. The overall comparison of the fruiting rates of the different treatments shows a very highly significant difference (χ^2 = 45.07; df = 3, P < 0.001). The two to two comparison of these percentages shows a significant difference between T1 and T2 treatments (χ^2_{2022} = 4.06; df = 1; P < 0.05) and very highly significant between the T1' and T2' treatments (χ^2_{2023} = 15.89; df = 1; P < 0.001). Entomophilous pollination would promote the formation of normal seeds. The numerical contribution of floricultural insects to the percentage of normal seeds is 5.87% in 2022 and 2023. The work of Negussie *et al.* (2013) in Zambia show that floricultural insects impacted by 4.5% on the number of normal seeds per capsule of this Euphorbiaceae. The fruiting rate was 100% for T3, 56.76% for T4, 100% for T3' and 57.97% for T4'. The overall comparison of these four percentages shows a very highly significant difference (χ^2 = 58.84; df = 3; P < 0.001). The two to two comparison of these percentages shows that the difference is very highly significant between the T3 and T4 treatments (χ^2_{2022} = 33.19; df = 1; P < 0.001), and between the T3' and T4' treatments (χ^2_{2023} = 24.00; df = 1; P < 0.001). The good quality of the fruits and seeds obtained in the protected treatments and then visited exclusively by *A. mellifera* could be explained by a large production of plant hormones (Souchon, 1965; Pouvreau, 2004) such as gibberellins, auxins, cytoquinine and ethylene that encourage the growth, ripening and enlargement of fruits and seeds (Meyer *et al.,* 2008). These results are similar to those of Brazil, Neves & Viana (2011) in their work on the pollinating efficiency of *A. mellifera* on the monoecious plants *J. mollissima* and *J. mutabilis* where *A. mellifera* improved the fruit yield of the latter by 100% and 85% respectively. The mean number of seeds per capsule was 2.92 for T3 treatment; 0.94 for T4 treatment; 2.92 for T3' treatment and 2.78 for T4' treatment. The overall comparison the means numbers of seeds per capsule of the different treatments shows a very highly significant difference (F = 7.33; df = 6; P < 0.001). The two to two comparison of the average number of seeds per capsule shows a very highly significant difference between the T3 and T4 treatments (t_{2022} = 12.69; df = 304; P < 0.001), and not significant between T3' and T4' (t_{2023} = 0.66; df = 254; P > 0.05). The contribution of *A. mellifera* was 2.11 in 2013 and 2.19 in 2014 according to the work of Népidé & Tchuenguem, (2016) on the flowers of *Croton macrostachyus* (Euphorbiaceae) at Dang. The percentage of normal seeds was 94.59% for the T3 treatment; 89.24% for the T4 treatment; 99.84% for the T3' treatment; 96.38% for the T4' treatment. The overall comparison of the fruiting rates of the different treatments shows a very highly significant difference (χ^2 = 33.92; df = 3, P < 0.001). The two to two comparison of these percentages shows a very highly significant difference between the T3 and T4 treatments (: χ^2_{2022} = 241.15 df = 1; P < 0.001) and between the T3' and T4' treatments (χ^2_{2023} = 129.42; df = 1; P < 0.001). These results would mean that the honey bee plays a very important role in the production of good quality seeds (Meyer *et al.,* 2008). The impact of *A. mellifera* was 78.60 in 2013 and 76.69 in 2014 on the flowers of *Croton macrostachyus* (Euphorbiaceae) according to the work of Népidé & Tchuenguem (2016) at Dang.

6 CONCLUSION

Jatropha curcas has a mixed allogamous-self-pollinated breeding regime, with a strong predominance of allogamy. At Maroua, respectively six and seven species of insects divided into three orders and six families visit the flowers of this Euphorbiaceae. The majority insect is *Apis mellifera* with 34.74% and 53.10% of visits in 2022 and 2023 respectively. This bee collects both nectar and pollen. The mean duration of a foraging visit is 2.92 seconds for nectar collection and 2.38 seconds for pollen collection. Comparison of the yields of flowers left in free pollination with those of flowers protected from insects shows a good production of fruits and seeds due mainly to pollinating insects including *A. mellifera*. Through its pollinating efficiency, this bee promotes a very high fruiting of the flowers visited. It is therefore necessary to maintain colonies of *A. mellifera* in the vicinity of *J. curcas* population to improve capsule production, seed quality and bee honey yield in the Far North.

7 REFERENCES

Abrol, DP. 2012. *Pollination biology*: *Biodiversity conservation and agricultural production.* Springer Dordrecht Heidelberg. London, 792 p.

Abdoulaye, D. (2018). Extraction and characterization of waxy extracts of *Jatropha curcas* seeds (L.) for biopesticide application. Master's thesis. University of Laval, Quebec, Canada. 76 p.

Alamu, OT, Amao, AO, Oke OA. and Suleiman, RA. (2013). Foraging behavior of three insect pollinators of *Jatropha curcas* in Samaru-Zaria, Nigeria. *International Journal of Advence Agricultural Resea rch*, pp.87-91.

Anguessin B. and Mapongmetsem PM. 2021. Ethnobotany and varietal characterization of *Jatropha curcas* L. in the Sudanian savannahs of North Cameroon. *Ethnobotany Research & Applications,* 21: 1-11.

Basga, E, Fameni, TS. and Tchuenguem, FF-N. 2018. Foraging and pollination activity of *Xylocopa olivacea* (Hymenoptera : Apidae) on *Vitellaria paradoxa* (Sapotaceae) flowers at Ouro - Gadji (Garoua, Cameroon). *Journal of Entomology and Zoology Studies*, 6 (3) : 1015 - 1022.

Christian, W, Kingha, TBM, Dongock, ND, Faibawa, E, and Tchuenguem FF-N. (2018) Exploitation of *Jatropha curcas*, *Senegalia polyacantha* and *Terminalia schimperiana* flowers by *Apis mellifera* (Hymenoptera: Apidae) at Dang (Ngaoundéré, Cameroon). *Journal of Entomology and Zoology Studies*, 6(2), 2072-2078.
https://www.entomoljournal.com

Azo'o, EM, Tchuenguem, FF-N. and Messi, J. 2011. Influence of the foraging activity of the entomofauna on Okra (*Abelmoschus esculentus*) seed yield. *International Journal of Agriculture & Biology*, 13 (5) : 761 - 765.

Azo'o, EM, Madi, A, Tchuenguem, FF-N. and Messi J. 2012. The importance of a single floral visit of *Eucara macrognatha* and *Tetralonia fraterna* (Hymenoptera : Apidae) in the pollination and the yields of *Abelmoschus esculentus* in Maroua, Cameroon. *African Journal of Agricultural Research*, 7 (18) : 2853 - 2857.

Azo'o, EM, Tchuenguem, FF-N. and Messi J. 2017. Biological diversity of the entomofauna associated with *Citrullus lanatus* (Cucurbitaceae) flowers and assessment of its impact on yields. *Journal of Entomology and Zoology Studies*, 5 (5) : 810 - 815.

Demarly, Y. (1977). *Genetics and plant breeding.* Masson, Paris. 577 p.

Chang-wei, L, Kun L, You C. and Yongyu S. (2007). Floral display and breeding system of *Jatropha curcas* L. *Forest. Stud. China* 9(2) :114–119.

Djakbé, JD, Ngakou, A, Christian, W, Faïbawa, E. and Tchuenguem, FF-N. 2017. Pollination and yield components of

Physalis minima (Solanaceae) as affected by the foraging activity of *Apis mellifera* (Hymenoptera: Apidae) and compost at Dang (Ngaoundéré, Cameroon). *International Journal of Agronomy and Agricultural Research*, 11 (3): 43 - 60.

Djonwangwé, D, Tchuenguem, FF-N, Messi, J. and Brückner D. 2011a. Foraging and pollination activities of *Apis mellifera adansonii* Latreille (Apidae) on *Syzygium guineense* var. *guineense* (Myrtaceae) flowers at Ngaoundéré (Cameroon). *Journal of Animal and Plant Sciences*, 10 (3) : 1325 - 1333.

Djonwangwé, D, Tchuenguem, FF-N. and Messi, J. 2011b. Foraging and pollination activities of *Apis mellifera adansonii* Latreille (Hymenoptera: Apidae) on *Ximenia americana* (Olacaceae) flowers at Ngaoundéré (Cameroon). *International Research Journal of Plant Science*, 2 (6) : 170 - 178.

Djonwangwé, D, Tchuenguem, FF-N, Messi, J. and Brückner, D. 2011c. Impact of the foragingactivity of Apis *mellifera adansonii* Latreille (Hymenoptera : Apidae) on the pollination and drop of young fruits of the shea tree *Vitellaria paradoxa* (Sapotaceae) in Ngaoundéré (Cameroun). *International Journal of Biological and Chemical Sciences*, 5 (4) : 1538 - 1551.

Djonwangwé, D, Pando, JB, Kameni, BAS, Bella, MMA, Tchuenguem, FF-N. and Messi, J. 2017. Impact of the foraging activities of Xylocopa *inconstans* Smith F. 1874 (Hymenoptera : Apidae) and *Megachile eurymera* Smith 1864 (Hymenoptera : Megachilidae) on pollination and fruit and seed yields of *Vigna unguiculata* (L.) Walp. 1843 (Fabaceae) in Maroua, Far North, Cameroun. *Afrique Science*, 13 (5) : 1 - 17.

Dounia, Tamesse, JL. and Tchuenguem, FF-N. 2016. Foraging and pollination activity of *Lipotriches collaris* Vachal 1903 (Hymenoptera : Apidae) on the flowers of *Glycine max* (L.) (Fabaceae) in Maroua - Cameroun. *Journal of Animal & Plante Sciences*, 29 (1): 4515 - 4525.

Douka, C, Tamesse, LJ. and Tchuenguem, FF-N. 2017. Impact of single visit of *Lipotriches collaris* Vachal 1903 (Hymenoptera : Halictidae) on *Phaseolus vulgaris* (Fabaceae) flowers at Maroua (Cameroon). *Journal of Applied Biology & Biotechnology*, 5 (2) : 72 - 76.

Fameni, TS, Tchuenguem, FF-N. and Brückner, D. (2012). Pollination efficiency of *Apis mellifera adansonii* (Hymenoptera: Apidae) on *Callistemon rigidus* (Myrtaceae) flowers at Dang (Ngaoundéré, Cameroon). *International Journal of Tropical Insect Science*, 32(1), 2-11.

Jacob-Remacle, A. (1989). Foraging behavior of domestic bees and wild bees in apple orchards in Belgium. Apidologie, 20, 217-285. https://hal.archives-ouvertes.fr/hal-00890783

Kabe, HK, Megueni, C, Tchobsala, Njintang, YN. and Tchuenteu, TL. (2019). Responses of *Jatropha curcas* (L.) to various types of fertilizations grown on-farm in the locality of Tandjilé in the South of Chad. *International Journal of Applied Research*, 5(5), 243-249.

Katembo, BI. and Gray, PS. (2007). Africa, seed and biofuel. *Journal of Multi-Disciplinary Research*, 1, 1 - 6.

Dymond, K, Celis-Diez, JL, Potts, SG, Howlett, BG, Willcox, BK, Garratt, MPD. 2021. The role of insect pollinators in avocado production : A global review. *Journal of Applied Entomology* 2021;145:369–383.

Kuete, M, Melingui, A, Mounkam, J. and Nofiele, D. (1993). New Geography of Cameroon. EDICEF, 207 p.

Maes, WH, Trabucco, A, Achten, WMJ. and Muys, B. (2009) Climatic growing conditions of *Jatropha curcas* L. *Biomass and Bioenergy* 33, 1481-1485.

Mateos-Fierro, Z, Garratt, MPD, Fountain, MT, Ashbrook, K, Westbury, DB. (2022). Wild bees are less abundant but show better pollination behaviour for sweet cherry than managed pollinators. *Journal of Applied Entomology*, 146:361–371.

Meyer, S, Reeb C. and Bosdeveix R. 2008. Botany, biology and plant physiology. Maloine (éd.), 490p.

Mohamadou, M, Ngakou A. and Tchuenguem FF-N. 2018. Integrated impact of mycorrhiza (*Glomus* sp.) and pollinating insects on growth and yield of *Vigna subterranea* (L.) Verdcourd (Fabaceae). *Journal of Animal & Plant Sciences*, 35 (2) : 5604 - 5622.

Negussie, A, Achten, WMJ, Verboven, HAF, Hermy, M. and Muys, B. (2013). Floral display and effects of natural and artificial pollination on fruiting and seed yield of the tropical biofuel crop *Jatropha curcas* L. GCB *Bioenergy*, 6, 210-218. https://www.researchgate.net

Népidé, NC. and Tchuenguem, FF-N. (2016). Pollination efficiency of *Apis mellifera adansonii* Latreille (Hymenoptera: Apidae) on *Croton macrostachyus* (Euphorbiaceae) flowers at Dang, Ngaoundéré, Cameroon. *International Journal of Biosciences*, 9 (3), 75-88. http://www.innspub.net

Neves, EL. and Viana, BF. (2011). Pollination efficiency of *Apis mellifera* Linnaeus, 1758 (Hymenoptera, Apidae) on the monoecious plants *Jatropha mollissima* (Pohl) Baill. and *Jatropha mutabilis* (Pohl) Baill. (Euphorbiaceae) in a semi-arid Caatinga area, northeastern. *Brazilian Journal of Biology*, 1, 107- 113. https://tinyurl.com/8xz7jmk4

Pananya, P, Savitree, M. and Chama, P. (2015). Diversity and Foraging Behavior of Dipteran Pollinators of Physic nut (*Jatropha curcas* L.) in Thailand. *Thai J. For*, 34(3), 1-15. https://li01.tci-thaijo.org/index.php/tjf/article/view/255376

Penjit, S. (2012). Prospect of Deoiled *Jatropha curcas* (L.) Seedcake as Fertilizer for Vegetables Crops -A Case Study. *Journal of Agricultural Science*, 4(3), 211-226. https://ccsenet.org/journal/index.php/jas/article/view/11792

Pouvreau A., 2004. Les Insectes pollinisateurs. Delachaux et Niestlé, Paris, 189 p.

Raju, AJS. and Ezradanam, V. (2002). Pollination ecology and fruiting behavior in a monoecious species, *Jatropha curcas* L. (Euphorbiaceae). *Current Science* 83, 1395-1398. https://www.researchgate.net/publication/237803315

Reddi, EUB. and Reddi, CS. (1983). Pollination ecology of *Jatropha gossypiifolia* (Euphorbiaceae). *Proceedings Indian Academy of Science* (Plant Science) 92(2), 215-231. https://link.springer.com/article/10.1007/BF03052976

Rincón-Rabanales, M, Vargas-López, LI, Adriano-Anaya, L, Vazquez-Ovando, A, Salvador-Figueroa, M. and Ovando-Medina I. (2016). Reproductive biology of the biofuel plant *Jatropha curcas* in its center of origin. *PeerJ* 4 :e1819 ; https://tinyurl.com/yhd9u5uv.

Roubik, DW, Shoko, S. and Hamid, KAA. 2005. *Pollination ecology and the rain forest.* Springer, New - York, 307 p.

Souchon, C. 1965. Insects and plants : what do i know ? PUF (éd), Paris, 128 p.

Taimanga and Tchuenguem, FF-N., 2018. Pollination efficiency of *Apis mellifera* Linnaeus 1758 (Hymenoptera, Apidae) on *Mimosa pudica* Linnaeus 1753 (Fabaceae) inflorescences at Yassa (Douala - Cameroon). *Journal of Entomology and Zoology Studies*, 6 (5) : 2027 - 2033.

Tchuenteu, TL, Megueni C. and Njintang, YN. (2013). A study of the variability for grain and oil yield and yield related traits of castor beans accessions in two savannah agro-ecological zones of Cameroon. *International Journal of Biosciences*, 3(8), 251-263.

Tchuenguem, FF.-N, Messi J. and Pauly A. (2001). Activity of *Meliponula erythra* on

Dacryodes edulis flowers and its impact on fruiting. *Fruits*, 56, 179-188.

Tchuenguem, FF-N, Pauly, A, Messi, J, Brückner, D, Ngamo, STL. and Basga, E. (2004). An Afrotropical bee specialized in collecting pollen from grasses (Poaceae): *Lipotriches notabilis* (Schletterer 1891). (Hymenoptera Apoidea Halictidae). *Annals of the Entomological Society of France*, 40 (2), 131-143. https://tinyurl.com/mrytrkaj

Tchuenguem, FF-N. (2005). Foraging and pollination activity of *Apis mellifera adansonii* Latreille (Hymenoptera: Apidae, Apinae) on the flowers of three plants in Ngaoundéré (Cameroon): *Callistemon rigidus* (Myrtaceae), *Syzygium guineense* var. *macrocarpum* (Myrtaceae) and *Voacanga africana* (Apocynaceae). State Doctoral Thesis, University of Yaoundé I, 103 p. http://dx.org/10.4314/ijbcs.v5i4.19

Tchuenguem, FF.-N. and Népide, NC. (2018). pollinator efficiency of *Apis mellifera* L. (Hymenoptera : Apidae) on *Sesamum indicum* (Pedaliaceae) var. White and Smooth seed in Dang (Ngaoundéré, Cameroon). *International Journal of Biological and Chemical Sciences*, 12 (1), 446 - 461.