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Floral activity of *Apis mellifera* (Hymenoptera: Apidae) on *Bidens steppia* (Asteraceae), *Cordia africana* (Boraginaceae), *Pittosporum viridiflorum* (Pittosporaceae) and *Psychotria mahonii* (Rubiaceae) in Nyambaka (Adamawa, Cameroon)

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Experiments were conducted at Nyambaka in the Adamawa Region of Cameroon, from March 2017 to November 2018, for assessing the apicultural potential of *Bidens steppia, Cordia africana, Pittosporum viridiflorum* and *Psychotria mahonii.* In order to improve the beekeeping productivity, it is important to investigate the diversity of bee plants in a given apiary site. To that end, the foraging behaviour of *Apis mellifera* workers was studied on the flowers of each plant species twice a week during the whole blooming period. The abundance of opened flowers per plant, floral products harvested by foragers, mean duration of floral visit, mean density of foragers, sugar content of nectar of each plant species, and number of effective visits of *A. mellifera* on flowers were assessed. Results indicated that, honeybee workers harvested nectar of each plant species; *B. steppia* and *P. viridiflorum* were intensely foraged for pollen harvesting too. The abundance of workers/1000 flowers varied from 123 on *P. mahonii* to 724 on *C. africana*. The mean value of the sugar content of nectar oscillated from 19.50% (*C. africana*) to 38% (*B. steppia*). *C. africana* and *P. mahonii* were highly nectariferous plant species while *B. steppia* was very highly polliniferous and slightly nectariferous and *P. viridiflorum* very highly nectariferous and slightly polliniferous. During its foraging activity, workers improved the pollination possibilities of plant species. By planting or protecting these plant species, a bee-friendly garden can be preserve for providing nectar flow and pollen availability for beekeeping purpose.

Key words: Apiary, apicultural value, beekeeping, bee plant, foraging behaviour, sugar content.

INTRODUCTION

Beekeeping is one of the most important cultural and economic activities in the Adamawa region of Cameroon (Ingram, 2011). The highest quantity of honey consumed or marketed in this country is from this region which has a suitable climatic condition for the proliferation of honeybees (INADES, 2000). Despite the favorable agro-ecology of honey production and the high number of bee colonies this region is endowed with, the honey production and productivity level in Cameroon is still very low (Dongock et al., 2017). Yet, sustainable beekeeping can be improved through the understanding and conservation of plants producing nutrient for the honeybees mainly in terms of nectar and pollen (El-Nebir and Talaat, 2013).

Apis mellifera is one of the bees raised on a large scale in beekeeping to produce honey and for pollination. This species comprises 28 subspecies including *Apis mellifera adansonii*, which has its origin from Africa (Fletcher, 1978). Honeybee workers are attracted commonly to plants that produce nectar and pollen. Nectar is a sweet substance that attracts bees which also need pollen in their diet (Louveaux, 1984). These food sources provide the nutritional requirements of the bee colonies. Nectar as a source of honey provides heat and energy while pollen provides protein, vitamins and fatty substances (Amsalu et al., 2003). During floral visits for nectar harvesting and pollen gathering, honeybees, in turn, pollinate plants; thus they can help in boosting fruit and seed yields of the host plant and then propagate their species (Klein et al., 2007; Allsopp et al., 2008).

The honey and other products of honeybees depend on the availability of floral resources in a given area (Amsalu et al., 2003). Intending to improve the level of honey production both in quantity and quality in the Adamawa region of Cameroon, several findings are available in enhancing beekeeping practice regarding the inventory of bee plants in some sites like Ngaoundere (Tchuenguem et al., 2010; Ingram, 2011; Djonwangwé et al., 2011; Egono et al., 2018; Wékéré et al., 2018) and Ngaoundal (Dongock et al., 2017).

Nyambaka is a small locality in the Adamawa region of Cameroon where beekeeping is still done on a small-scale. In this area, beekeeping practice appears like a commercial enterprise; it offers not only diverse hive products which can be sold in local markets and become an important source of regular income for farmer families, but also provide complementary services, such as plant pollination. Moreover, locally, bee products improve farm family nutrition and can provide traditional health care remedies. There are many plant species that produce a large amount of nectar and pollen for bees to be collected in the locality. Some of these plants are important as they provide bees with a surplus of honey. Small-scale beekeeping is considered as an important occupation that contributes significantly to livelihood security in that region. Yet, most of the honey is produced with traditional hives consisting of bast and grass; besides, bee plants are not yet well known by beekeepers in this area. It is, therefore, an important practice to help bees in their survival by adding to the shrinking inventory of flower-rich habitat in the study locality.

The United Nations World Health Organization estimates that as many as 5.6 billion people, 80% of the world population, utilize herbal medicine for primary health care (Shen et al., 2012). *Bidens steppia* (Steetz) Sherff (Asteraceae), *Cordia africana* Lam. (Boraginaceae), *Pittosporum viridiflorum* Sims (Pittosporaceae), and *Psychotria mahonii* C.H. Wright (Rubiaceae) are four multipurpose plant species which are often harvested for local use as food and medicine in Nyambaka. In the locality, different preparations of parts of *B*. *steppia* plant are commonly purported to treat several categories of illnesses such as diabetes and malaria. In the literature, extracts of *B*. *steppia* have antitumor (Sundararajan et al., 2006), anti-inflammatory, antimicrobial (Pereira et al., 1999), antidiabetic, antimalarial (Tobinaga et al., 2009) properties. *C*. *africana* is used as firewood. The fruit pulp of this plant is edible and is added as a sweetener to food. The leaves serve as fodder for livestock. Leaf decoctions are administered to treat headache, nose bleeding, dizziness and vomiting during pregnancy, wounds and worms while root decoctions are drunk to treat jaundice (Obeng, 2010). The categories to which *P*. *viridiflorum* is used in traditional medicine include wounds, treatment of veterinary ailments, gastrointestinal tract and sexually transmitted diseases, circulatory and inflammatory disorders, as well as diseases such as cancer, tuberculosis, and malaria (Madikizela and McGaw, 2017). As for *P*. *mahonii*, fresh rhizomes are chewed and the juice swallowed to treat intestinal tract diseases and worms.

In addition to their medicinal importance, all four plant species studied have flowers that produce nectar and pollen available for bee species. It is well known in the literature that the productivity of the honeybee colonies is proportional both to the abundance and attractiveness of the nectariferous and polliniferous plants present in the environment of the apiary (Williams and Carreck, 1994; Van't et al., 2005). Thus, sustainable beekeeping in a given region requires detailed knowledge of the apicultural value of plant species that grow there for their optimal management (Dongock et al., 2017). Moreover, honeybee being a bio-indicator species (Porrini et al., 2003), medicinal plants are an interesting source for the production of honey with medicinal biological activity very close to their floral origin (Liberato et al., 2011). That is why it is interesting to associate a crop of medicinal

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plants with beekeeping. However, there is no available data published on the relationships between African honeybees and many local and medicinal plant species including *B. steppia*, *C. africana*, *P. viridiflorum* and *P. mahonii* in Cameroon. The main objective of the present research work was to determine the apicultural status of these plant species in Nyambaka, to improve the beekeeping potential and enhance the value of the plants studied in this locality. For each plant species, we recorded the foraging activity of *A. mellifera* on flowers and estimated its apicultural value.

MATERIALS AND METHODS

Study site and biological material

The present study was carried out from March 2017 to November 2018 in Nyambaka, a village located in the South of Ngaoundere, the capital of the Adamawa region of Cameroon. This region is located between the 6th and 8th degrees of latitude north and between the 11th and 15th degrees of longitude east; it belongs to the high-altitude Guinean Savannah agro-ecological zone (Djoufack et al., 2012). The climate is characterized by a rainy season (April to October) and a dry season (November to March), with an annual rainfall of approximately 1500 mm, a mean annual temperature of 22°C, and a mean annual relative humidity of 70% (Amougou et al., 2015) which are suitable climatic conditions for the beekeeping practice. Plants chosen for observations were located in an area of 1.5 km in diameter, centered on a Kenyan top-bar hive of *A. mellifera* colony. The hive was located at the following coordinates: 6°89'62'943'N, 14°09'28'038'E, 1136 m a.s.l.

The animal material included many insect species naturally present in the environment. The number of honeybee colonies located in the area varied from 60 in March 2017 to 69 in November 2017 and from 42 in March 2018 to 72 in November 2018. Apart from the honeybee colonies located in the experimental site, other colonies around the experimental site have not been inventoried since the radius action of foragers may exceed 12 km around the hive (Louveaux, 1984). The vegetation was represented in the study site by crops, ornamental plants, hedge plants and native plants of savannah and gallery forests.

Study of the foraging activity of *A. mellifera* on flowers

From March 2017 to November 2018, the foraging behaviour of *A. mellifera* workers was recorded on flowers of different plant species. Data were registered twice a week, between 07:00 a.m. and 06:00 p.m., at three-time intervals per day: 07:00-11:00 a.m., 11:00 a.m.-03:00 pm and 03:00-06:00 p.m. For any plant species visited by the honeybee browsers and for each investigation date, the following parameters were registered for each time frame and, whenever possible: the number of effective visits (the bee came into contact with the stigma) (Jacob-Remacle, 1989; Freitas, 1997), the mean duration of visits using a stopwatch (Tchuenguem et al., 2004). The density of foragers (highest number of individuals foraging simultaneously on a flower or 1000 flowers) was also assessed. The density of foragers was recorded following the direct counting on the same dates and daily periods as for the registration of the duration of individual flower visits; for this purpose, some foragers were counted on a known number of flowers. The density of foragers per 1000 flowers (A_{1000}) was then calculated using the following formula: $A_{1000} = ((Ax/Fx)*1000)$ where *Fx* and *Ax* are the numbers of opened flowers and the number of foragers effectively counted on these flowers at a given time *x* (Tchuenguem et al., 2004). The disruption of the activity of foragers by competitors and the attractiveness exerted by other plant species on *A. mellifera* was assessed by direct observations.

Evaluation of the sugar content of the nectar of different plant species

The concentration in total sugar of the nectar is an important parameter for the attractiveness of the honeybee concerning many flowers (Philippe, 1991). This parameter was determined with a handheld refractometer (0-90% Brix) and a thermometer that gave the ambient temperature, from March 2017 to November 2018. *A. mellifera* workers in full activity of nectar harvesting were captured on flowers and anesthetized by introducing them in a small jar containing cotton moistened with chloroform. The nectar was then removed from honeybee crop by exerting pressure on the bee abdomen placed between the thumb and the forefinger of the experiment; the nectar in the mouth was then expelled and its concentration in total sugars measured in g/100 dry matter (Tchuenguem et al., 2007). The registered values obtained were corrected according to the ambient temperature, using a table provided by the device leaflet (Cruden and Hermann, 1983).

Evaluation of the apicultural value of different plant species

As for other plant species, the apicultural value of each plant species studied was assessed using data on the flowering intensity, the degree of attractiveness of *A. mellifera* workers to nectar and/or pollen (Villières, 1987; Népidé et al., 2016).

Evaluation of the influence of *Apis mellifera* on pollination

To evaluate the ability of *A. mellifera* to act as a pollinator of each plant species during the nectar harvesting, the number of time a forager came into contact with the stigma of the visited flower was noted (Freitas, 1997). This approach allows highlighting the involvement of *A. mellifera* in self-pollination and cross-pollination (Zumba et al., 2013; Potts et al., 2015).

Statistical analysis

Data were subjected to descriptive statistics using SPSS 16. The Student's *t-test* was used for the comparison of means between two samples and Chi-square ($\chi 2$) for the comparison of two percentages. The analysis of variance (ANOVA) was used for multi-comparison of means.

RESULTS

Characteristics of the plant species studied

Tables 1 and 2 described plant species studied and the relative abundance of opened flowers per month for each of these plant species during both observation years. It is indicated from these tables that apart from *C. africana* which is mainly cultivated in the locality for the fruit production and shady purposes, *B. steppia*, *P. viridiflorum* and *P. mahonii* are respectively a shrub and small trees which grow spontaneously in the savannah.

Table 1. Scientific name, botanic family, biotope, some characteristics and strength of different plants studied.

Scientific name and status	Family	Biotope	Flowering period	DCOF	Number of plants	
					2017	2018
Bidens steppia (++; sh)	Asteraceae	Savannah	June-November	Yellow-orange	3634	4275
Cordia africana (+; tr)	Boraginaceae	Garden	June-September	White	23	25
Pittosporum viridiflorum (++; tr)	Pittosporaceae	Savannah	March-June	Greenish-white	764	716
Psychotria mahonii (++; tr)	Rubiaceae	Savannah	March-July	White	527	585

+: cultivated plant; ++: spontaneous plant; tr: tree; sh: shrub; DCOF: dominant colour of flowers.

Table 2. Relative abundance of opened flowers on each plant species per month during the two investigation periods.

Plant species	March 2017 to November 2017									March 2018 to November 2018								
	M	A	Ma	J	Ju	Au	S	O	N	M	A	Ma	J	Ju	Au	S	O	N
Bidens steppia					*	**	****	****	**				*	**	**	***	****	**
Cordia africana				**	****	****	**	*					*	****	***	**	*	
Pittosporum viridiflorum	*	***	****	**						*	***	****	**					
Psychotria mahonii	**	****	***	**	*					**	***	****	**	*				

M : March ; A : April ; Ma : May ; J : June ; Ju : July ; Au : August ; S : September ; O : October **;** N : November ; *: ≤100 flowers = rare; ** : >100 and ≤500 flowers = little abundant; ***: >500 and ≤1000 flowers = abundant; ****: >1000 flowers = very abundant.

The color of the flowers of these plant species varied from orange-yellow, greenish-white and white respectively for *B*. *steppia*, *P*. *viridiflorum*, *C*. *africana* and *P. mahonii*. Furthermore, the number of these plant species varied from about 25 for *C*. *africana* to about 4275 for *B*. *steppia*. These important numbers of plant species in the studied area enabled the availability of a large amount of floral mass during their blossoming.

A. mellifera foraging activity on flowers

Floral products harvested, intensity and frequency of collection of different products

The identity of the food harvested by *A*. *mellifera* workers from the flowers of each plant species investigated and the intensity and frequency of the collection of different food resources are presented in Table 3. The main results from this table indicated that: (a) *B*. *steppia* was weakly visited for nectar gathering while its pollen was highly attractive for *A. mellifera* workers (b) *P. viridiflorum* was slightly visited for its pollen while its nectar was abundantly harvested by honeybee foragers; (c) *C*. *africana* and *P*. *mahonii* were only visited for supplying nectar needs of *A*. *mellifera* as their pollen was scarcely collected. In general, the intensity of nectar or pollen collection varied with plant species and for a given plant species with the time.

The distribution of nutritive substances harvested by *A. mellifera* on flowers in terms of nectar and/or pollen of a given plant species according to each observation time interval is reported in Table 4. *A*. *mellifera* workers foraged nectar and/or pollen of *B. steppia*, *C. africana*, *P. viridiflorum* and *P. mahonii* almost during the whole daily period, from 06:00 a.m. till 06:00 p.m. and during all the blooming period of each plant species studied. This is an illustration that these plant species are important and abundant sources of nutrients for *A*. *mellifera*.

Density of foragers

The values of the density of foragers are reported

Table 3. Floral products harvested by *A. mellifera* from the flowers of plants according to period, harvesting intensity and abundance of food.

Plant species	*Variation of food harvesting according to the time period*																						
	March to November 2017									**March to November 2018**									**Seasonal frequency of food harvesting**				
	M	**A**	**Ma**	**J**	**Ju**	**Au**	**S**	**O**	**N**	**M**	**A**	**Ma**	**J**	**Ju**	**Au**	**S**	**O**	**N**	**TD**	**nDN**	**pDN**	**nDP**	**pDP**
B. steppia					P^1	N^1P^2	N^2P^4	N^2P^4	P^2				P^1	P^2	N^1P^2	N^2P^4	N^2P^4	P^2	96	32	33%	100	100%
C. africana				N^1	N^4	N^3	N^2	N^1					N^1	N^4	N^3	N^3	N^1		64	64	100%	**-**	-
P. viridiflorum	N^2	N^3	N^4P^1	N^4P^1						N^1	N^3P^1	N^4P^2	N^4P^1						64	64	100%	32	40%
P. mahonii	N^2	N^4	N^3	N^2	N^1					N^1	N^3	N^4	N^2	N^1					80	80	100%	**-**	-

M: March; A: April; Ma: May; J: June; Ju: July; Au: August; S: September; O: October; **N**: November; TD: Total number of observation days; nDN: number of days where the collection of nectar was effective; pDN: percentage of days were the collection of nectar was effective; nDP: number of days where the collection of pollen was effective; pDP: percentage of days where the collection of pollen was effective; N: Nectar; P: Pollen; 1, 2, 3 and 4 given as superscripts indicate the harvesting intensity which was very low, low, high and very high respectively.

Table 4. Products harvested by *Apis mellifera* from the flowers of the four plants species according to daily time interval.

Plant species	Daily time interval		
	07.00 - 11.00 am	**11.00 am - 3.00 pm**	**3.00 - 6.00 pm**
Bidens steppia	Pollen and nectar	pollen	Pollen and nectar
Cordia africana	Nectar	Nectar	Nectar
Pittosporum viridiflorum	Nectar and pollen	Nectar	Nectar and pollen
Psychotria mahonii	Nectar	Nectar	Nectar

Table 5. Abundance of *Apis mellifera* workers per 1000 flowers according to plant species and months.

Plant species	**March 2017 to November 2017**									**March 2018 to November 2018**								
	M	**A**	**Ma**	**J**	**Ju**	**Au**	**S**	**O**	**N**	**M**	**A**	**Ma**	**J**	**Ju**	**Au**	**S**	**O**	**N**
Bidens steppia					4	69	413	571	26				1	13	102	541	552	13
Cordia africana				18	504	724	107	7					6	430	643	132	13	
Pittosporum viridiflorum	5	462	607	26						17	362	702	10					
Psychotria mahonii	13	521	193	94	17					7	123	684	231	21				

M : March ; A : April ; Ma : May ; J : June ; Ju: July ; Au : august ; S : September ; O : October ; N : November.

in Table 5. The highest number of *A. mellifera* workers foraging simultaneously per flower was one for each plant species. The mean abundance per 1000 flowers in 2017 was 216 (n = 240; s = 122; maximum = 517) on *B. steppia*, 272 (n = 197; s = 143; maximum = 727) on *C. africana*,

Table 6. Duration of *Apis mellifera* visits on flowers of the four plants species according to the study periods and harvested products.

Plant species	March-November 2017 Mean duration of visit (sec)				March-November 2018 Mean duration of visit (sec)				Comparison of means of the two study periods		
	n	*m ± sd*	*mini*	*maxi*	*n*	*m ± sd*	*mini*	*maxi*	*t- value*	*df*	*p- value*
Bidens steppia (N)	205	5.27 ± 2.73^{a}	1	16	241	5.14 ± 2.53^{a}	1	12	0.52	444	$> 0.05^{NS}$
Bidens steppia (P)	245	6.42 ± 3.86^{b}	2	21	451	6.14 ± 5.24^{b}	1	13	0.73	694	$> 0.05^{NS}$
Cordia africana (N)	253	5.03 ± 2.21^{a}	2	15	306	5.28 ± 2.04^{a}	2	14	1.39	557	$> 0.05^{NS}$
Pittosporum viridiflorum (N)	234	3.92 ± 2.66^{c}	1	15	237	3.88 ± 2.49^{c}	1	12	0.17	469	$> 0.05^{NS}$
Pittosporum viridiflorum (P)	97	3.54 ± 2.48^{c}	1	12	106	4.10 ± 2.16^{c}	1	11	1.72	201	$> 0.01^{NS}$
Psychotria mahonii (N)	552	4.48 ± 1.92^{ac}	1	11	172	4.55 ± 1.91^{ac}	2	12	0.42	722	$> 0.05^{NS}$

n: sample size; m: mean; mini: minimum; maxi: maximum; N: Nectar collection visits; P: Pollen collection visits; sd = standard deviation ; NS = Non significant. Mean values in the same column (mean duration of a bee visit for nectar or pollen harvesting as a function of a given plant species) or in the same line (for a given plant species as function of the floral product harvested and the year) but with different letters vary significantly (P < 0.05).

271 (n = 146; s = 131; maximum = 643) on *P. viridiflorum* and 167 (n = 205; s = 94; maximum = 727) on *P. mahonii*. In 2018, the corresponding figures was 203 (n = 268; s = 118; maximum = 552) on *B. steppia*, 244 (n = 217; s = 128; maximum = 643) on *C. africana*, 272 (n = 116; s = 142; maximum = 702) on *P. viridiflorum* and 213 (n = 189; s = 121; maximum = 684) on *P. mahonii*. The optimal value of the density of *A. mellifera* workers corresponded with the month of the peak of blossoming of each plant species studied which are: September and October for *B. steppia*, July to August for *C. africana*, April and May for *P. viridiflorum* and *P. mahonii* respectively. The difference of the mean density of foragers was not significant for each plant species according to the year.

Duration of visits

Results from Table 6 highlighted the variation of the mean duration of *A. mellifera* visit as a function of the floral product harvested and for a given plant species according to the year. As pollen grains of *C. africana* and *P. mahonii* were not so interesting for foragers, only the mean duration of a visit for pollen collection by *A. mellifera* on *B. steppia* and *P. viridiflorum* were registered in both years. Overall, the duration of a forager visit varied with the floral product searched for and for a given product with the host plant species studied. The difference was significant between pollen and nectar gathering on *B. steppia* in 2017 (t = 5.23; df = 448; P < 0.05) and 2018 (t = 3.97; df = 690; P < 0.05), between nectar collection among plant species in 2017 (F = 6.52; df = 3, 1240; P < 0.05) and 2018 (F =5.93; df = 3, 952; P < 0.05) and between pollen collection on *B. steppia* and *P. viridiflorum* in 2017 (t = 7.63; df = 340; P < 0.05) and 2018 (t = 6.57; df = 555; P < 0.05). Workers of *A. mellifera* were disturbed during their foraging activity by other flower-visiting insects or abiotic parameters such as the wind and the rainfall. Some disturbances have resulted in the interruption of some honeybee visits and consequently reduced the time spend on the corresponding flower, thus obliged foragers to move swiftly from flower to flower.

Influence of neighboring flora

During the observation periods of each of the four plant species under investigation, flowers of many other plant species growing in the study area were visited by *A. mellifera* for nectar (ne) and/or pollen (po). Among these plants were, *Manihot esculenta* (Euphorbiaceae: ne), *Tithonia diversifolia* (Asteraceae: ne), *Bidens pilosa* (Asteraceae: ne + po), *Stylosanthes guianensis* (Fabaceae: ne + po), *Hibiscus rosa-sinensis* (Malvaceae: ne + po), *Sida rhombifolia* (Malvaceae: ne + po), *Terminalia schimperiana* (Combretaceae: ne + po), *Terminalia macroptera* (Combretaceae: ne + po), *Sesbania pachycarpa* (Fabaceae : ne + po), *Mimosa invisa* (Mimosaceae: po), *Mimosa pudica* (Mimosaceae: po), *Senna mimosoides* (Fabaceae: po), and *Zea mays* (Poaceae: po). During one foraging trip, a forager was not observed moving from the flowers of a given plant

Table 7. Concentration in total sugar of the nectar of plant species studied.

Plant species	Concentration in total sugar of the nectar (%)										
	March 2017 to November 2017				March 2018 to November 2018				Comparison of means of the two study periods		
	n	m ± s	mini	maxi	n	m ± s	mini	maxi	t	ddl	P
Bidens steppia	62	38.07 ± 9.60[a]	22	47	45	36.29 ± 9.69[a]	23	46	0.94	105	> 0.05[NS]
Cordia africana	60	19.43 ± 3.42[b]	10	21	73	19.05 ± 3.25[b]	10	22	0.65	131	> 0.05[NS]
Pittosporum viridiflorum	46	29.54 ± 6.63[c]	21	36	69	28.84 ± 6.14[c]	21	34	0.58	113	> 0.05[NS]
Psychotria mahonii	37	26.03 ± 1.03[c]	23	27	43	25.97 ± 0.96[c]	23	27	0.26	78	> 0.05[NS]

Mean values in the same column (plant species) or in the same line (for a given parameter as function of the year) but with different letters vary significantly (P < 0.05).

species studied to the neighboring plant species and conversely.

Concentration in total sugar of the nectar of plant species studied

Results from Table 7 reported the mean concentration in total sugar of *B. steppia* nectar was 38.07% (n = 62; s = 9.60) in 2017 and 36.29% (n = 45; s = 9.69) in 2018. The difference between these means is not significant (t = 0.94; df = 105; P > 0.05). The mean concentration in total sugar of the *C. africana* nectar was 19.43% (n = 60; s = 3.42) in 2017 and 19.05% (n = 73; s = 3.25) in 2018. The difference between these two means is not significant (t = 0.65; df = 131; P > 0.05). The mean concentration in total sugars of *P. viridiflorum* nectar was 29.54% (n = 46; s = 6.63) in 2017 and 28.84% (n = 69; s = 6.14) in 2018. The difference between these means is not significant (t = 0.58; df = 113; P > 0.05). The mean concentration in total sugar of *P. mahonii* nectar was 26.03% (n = 37; s = 1.03) in 2017 and 25.97% (n = 43; s = 0.96) in 2018. The difference between these means is not significant (t = 0.26; df = 78; P > 0.05). The difference was significant between the four plant species concerning this parameter in 2017 (F = 7.14; df = 3, 201; P < 0.05) and in 2018 (F =5.31; df = 3, 226; P < 0.05). Overall, the concentration in total sugar of the nectar varies following plant species.

Apicultural value of the plant species

During the flowering period of each plant species studied, we recorded distinct levels of activity of *A. mellifera* workers on the flowers. There were a high availability of flowers, a high density of workers per tree or shrub, a good nectar collection on all plant species and high pollen harvest on *B. steppia* but a low pollen collection on *P. viridiflorum*. Moreover, in the dry season, which is the main period of honey flow, individual tree of *P. viridiflorum* and *P. mahonii* investigated could produce more than 70.000 flowers. On the other hand, during the rainy season (period of the food shortage within honeybee colonies), individual tree of *B. steppia* and *C. africana* could averagely produce up to 15.000 flowers. Considering these data, the plant species studied can be classified based on their apicultural value as follows: (a) very highly nectariferous: *C. africana, and P. mahonii*; (b) very highly polliniferous and slightly nectariferous: *B. steppia* (c) very highly nectariferous and slightly polliniferous: *P. viridiflorum*. Table 8 summarizes the appropriate period for the optimal nectar and/or pollen availability in Nyambaka in 2017 and 2018. Thus, in this study area, the nutritional requirements of honeybees are provided by *B. steppia* from August to September, *C. africana* from June to August while *P. viridiflorum* and *P. mahonii* were important suppliers of nectar to foragers from April to May.

Impact of A. mellifera activity on the pollination of the plant species

During the collection of pollen or nectar on the flowers of the four plant species studied, foragers regularly contacted anthers and carried pollen. With this pollen, they flew frequently from flower to flower. The percentage of the total number of visits during which worker bees came into contact with the stigma of the visited flower was 100% for

Table 8. Apicultural value of plant species studied and the most favorable period for bees to harvest nectar and/or pollen.

Plant species	Floral product harvested		
	Nectar	Pollen	Intense blooming period
Bidens steppia	**	****	September-October
Cordia africana	****	-	July-August
Pittosporum viridiflorum	****	**	April-May
Psychotria mahonii	****	-	April-May

**** = very high nectariferous or polliniferous; ** = slightly nectariferous or polliniferous.

Table 9. Number and frequency of contacts between *Apis mellifera* and the stigma during the floral visits to three plant species.

Plant species	March-November 2017			March-November 2018			Total		
	Number of studied visits	Visits with stigmatic contact		Number of studied visits	Visits with stigmatic contact		Number of visits studied	Visits with stigmatic contact	
		Number	%		Number	%		Number	%
Bidens steppia	450	450	100.00	692	692	100.00	1142	1142	100.00
Cordia africana	253	253	100.00	306	306	100.00	559	559	100.00
Pittosporum viridiflorum	331	331	100.00	343	343	100.00	674	674	100.00
Psychotria mahonii	552	552	100.00	172	172	100.00	724	724	100.00

Number and frequency of contacts comparison: (*Bidens steppia*) : χ2 2017/2018 = 0.00 ; *df* = 1; $P > 0.05^{NS}$; (*Cordia africana*) : χ^2 2017/2018 = 0.00 ; *df* = 1 ; $P > 0.05^{NS}$; (*Pittosporum viridiflorum*) : χ^2 2017/2018 = 0.00 ; *df* = 1 ; $P > 0.05^{NS}$; (*Psychotria mahonii*) : χ^2 2017/2018 = 0.00 ; *df* = 1 ; $P > 0.05^{NS}$; (*B. steppia*, *C. africana*, *P. viridiflorum, Ps. mahonii*) : χ^2 2017 = 0.00 ; *df* = 3; $P > 0.05^{NS}$; (*B. steppia*, *C. africana*, *P. viridiflorum, P. mahonii*) : χ^2 2018 = 0.00; *df* = 3 ; $P > 0.05^{NS}$.

B. steppia, *C. africana P. viridiflorum* and *P. mahonii* during the 2017 as well as the 2018 investigation period (Table 9). Consequently, *A. mellifera* workers strongly increase the pollination possibilities of *B. steppia*, *C. africana*, *P. viridiflorum* and *P. mahonii.*

DISCUSSION

In Nyambaka, an important area for beekeeping practice in the Adamawa region of Cameroon, the four plant species studied have shown their importance as sources of pollen and nectar for African honeybees. Previous works have already been done in other countries which have shown the immense potential that some of these plant species abounded in the local beekeeping practice. That is the case for *C. africana* which was mentioned in the Western Amhara region of Ethiopia as a major honeybee plant (Tesfa et al., 2013); moreover, the pollen of this plant species was identified as the secondary pollen source in four honey samples collected from Salika village in Ethiopia (Tewelde, 2006). The collection of the nectar of *P. psychotroides* by *A. mellifera*, another plant species belonging to the genus *Psychotria*, has already been reported in previous investigations in the Adamawa Region (Dongock et al., 2017). In Benin, Yédomonhan et al. (2009) found that, on the flowers of *Psychotria* spp., *A. mellifera* harvested both pollen and nectar widely. In the southern highland of Tanzania, the flowers of *B. steppia* and *P. viridiflorum* were mentioned as an important source for both pollen and nectar collection all day long and during the whole flowering period (Latham, 2015). In Bujumbura (Burundi), *B. steppia* flowers were mainly visited by the honeybee (Ndayikeza et al., 2014) for both nectar and pollen collection. Overall, the substance harvested by *A. mellifera* from flowers (nectar or pollen) on a given plant species can vary with regions. The variations observed in this study could be explained mainly by the real needs of the colonies from which originated honeybee workers (Segeren et al., 1996). The good nectar collection observed in the four plant species is the fact that, bees can collect nectar with sugar concentrations below 15-85% under natural conditions (Roubik and Buchmann, 1984).

From our fieldwork, the colors of the flowers of the studied plant species are among the most attractive for honeybee foragers. According to Bergström (1982), the bright colors are the most attractive for the flower-visiting insects in general and honeybees in particular because those are among the colors they can easily perceive. Indeed, bees have a much broader range of color vision. Their ability to see ultraviolet light gives them an advantage when seeking nectar and pollen (Dyer and Garcia, 2014). Thus, to identify the most profitable flowers, and avoid non-rewarding flowers like mimics (Dafni, 1984), bees make use of several cues including color (Hempel et al., 2001) information. Furthermore, several other parameters such as the accessibility of nectar and/or pollen, the availability of both products, the floral mass or number of flowers or inflorescences bearded by a plant species are important for the good practice of beekeeping elsewhere (Segeren et al., 1996).

Another important aspect from the present study is the possibility of the mastery of the period when the blossoming of each plant species studied is effective and optimal yearly. Indeed, the knowledge of these time intervals makes it possible to establish the apicultural calendar in avoiding pollen and nectar scarcity and shortage (Chigere et al., 2014). For this purpose, the supply of *A*. *mellifera* foragers with nectar and/or pollen in a well-known period of the year is already possible for *B*. *steppia*, *C*. *africana*, *P. viridiflorum* and *P. mahonii* in the study site.

The observed high abundance of foragers per 1000 flowers recorded in this study could be attributed to the ability of honeybees to recruit a great number of workers for the exploitation of high-yield food sources (Frisch, 1969; Kajobe, 2006). Honeybees can smell or detect pollen or nectar odor (Free, 1970) using sensory receptors located on the flagellum of their antennae. Worker honeybees dance inside the nest after a successful foraging trip to communicate with their congeners, information about the food odor, the distance and the direction from the hive to the food source (Frisch, 1967). The round dance is performed when the resource is within 100 meters from the hive, while the wagging dance takes place for the resource 100 meters away from the hive (Frisch, 1967).

Significant differences observed between the duration of pollen harvesting visit and that of nectar harvesting on the flowers of *B. steppia* could be explained by the accessibility of each of these floral products. On the flower of *B. steppia*, pollen is a product in great quantity and is easily accessible to bees. In these conditions, honey bee workers can obtain their pollen load by visiting a few flowers during a foraging trip. That is why *A. mellifera* spent more time on a flower for pollen harvesting than for nectar in *B. steppia.* Therefore, on each of the four plant species, *A. mellifera* spent more time on a flower for nectar collection of *C. africana, B. steppia, P. mahonii* and *P. viridiflorum* respectively. The fact that *A. mellifera* spent significantly different time on a flower of different species for nectar and pollen collection could be explained by the abundance and/or the accessibility to each of these floral products.

The disruptions of visits by other insects reduced the duration of certain *A. mellifera* visits. This obliged some workers to visit more flowers during a foraging trip, to maximize their pollen or nectar loads. Similar observations were made for *A. mellifera* workers foraging on flowers of *Entada africana* (Fabaceae), *Eucalyptus camaldulensis* (Myrtaceae), *Psidium guajava* (Myrtaceae) and *Trichillia emetica* (Meliaceae) (Tchuenguem et al., 2007), *Combretum nigricans* (Combretaceae), *Erythrina sigmoidea* (Fabaceae), *Lannea kerstingii* (Anacardiaceae), *Vernonia amygdalina* (Asteraceae) (Tchuenguem et al., 2010), *Jatropha curcas* (Euphorbiaceae), *Senegalia polyacantha* (Mimosaceae) and *Terminalia schimperiana* (Combretaceae) (Wékéré et al., 2018)

The present study shows that during one foraging trip, an individual bee foraging on a given plant species scarcely visited another plant species. This result indicates that *A. mellifera* shows flower constancy (Louveaux, 1984) for the flowers of each of the four plant species studied. This floral constancy in honeybees exists because an individual forager is generally capable of memorizing and recognizing the shape, color, and odor of the flowers visited during previous foraging trips (Hill et al., 1997; Wright et al., 2002). The flower constancy of *A. mellifera* has been demonstrated on flowers of several other plant species among which are *Jatropha curcas* (Euphorbiaceae), *Senegalia polyacantha* (Mimosaceae) and *Terminalia schimperiana* (Combretaceae) (Wékéré et al., 2018), *Lannea kerstingii* (Anacardiaceae) and *Ximenia americana*. (Olacaceae) (Djonwangwé et al., 2011), and *Callistemon rigidus* (Myrtaceae) (Fameni et al., 2012). The faithfulness of the honeybee to the flowers of the plant species studied can also be explained, in part, by the fact that their nectar is rich in sugars; Philippe (1991) suggested that foragers could not allow their colony to record a net energy gain if the sugar concentration of the harvested nectar is less than 20%.

Considering this minimum limit, browsers can allow their colony to gain a lot of energy when they collect nectar from plant species studied.

During the collection of nectar and/or pollen on each flower, *A. mellifera* workers regularly come into contact with the stigma and anthers. They could thus enhance self-pollination, which has been demonstrated for other plant species in the past (Anderson and Symon, 1988; Lewis et al., 1999; Otiobo et al., 2015). *A. mellifera* could induce cross-pollination through carrying of pollen with their furs, legs and mouth accessories, which is subsequently deposited on another flower belonging to different plants of the same species (Abrol, 2012).

Conclusion

At Nyambaka, *A. mellifera* workers harvested intensely and regularly the nectar and pollen of *B*. *steppia, C*. *africana, P*. *viridiflorum* and *P*. *mahonii* flowers. These results suggest that these plants are the highly nectariferous and polliniferous floral plant able to substantially contribute to maintaining the nutritional needs of the honeybee colony. All these plant species contributed more or less to the feeding and therefore to the strengthening of the honeybee colonies. *A*. *mellifera* workers increased the pollination possibilities of each plant species. Based on our results, we recommend: (a) the installation of *A. mellifera* colonies in environments where one or more of the studied plant species occur abundantly and (b) the plantation and/or protection of each plant species in the surrounding of *A. mellifera* apiaries. These precautions will allow, in addition to improving the production of honey in the study location, its enrichment in various therapeutic properties for the well-being of the local populations. The impact of *A. mellifera* on fruit or grain yields of each plant species studied via its pollination efficiency will be looked at in future works.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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