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Research Article
Pollination and Phenological Study of *Balanites aegyptiaca* (L.) Del. in the Sudano-Sahelian Zone (Far North, Cameroon)

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Abstract

Background and Objective: *Balanites aegyptiaca* products are valuable resources for local African populations. However, the production of these products is low due to lack of knowledge on its pollination and phenology. To contribute to the development, sustainable management and socio-economic importance of this Sahelian species, a study was carried out in the Sudano-Sahelian Zone of Cameroon. **Materials and Methods:** To achieve the set objectives, an approach combining two methods was adopted. The inventory of visiting agents, based on capture in two phases (diurnal and nocturnal) of the insects observed on the feet of *B. aegyptiaca* and an evaluation of the phenological phases based on the monitoring and counting of plant organs. **Results:** A total of 7 orders of insects (Hymenoptera, Diptera, Lepidoptera, Hemiptera, Dictyoptera, Orthoptera and Coleoptera) have been identified on *B. aegyptiaca*. The Hymenoptera order is the most dominant with a higher number of insects. *Balanites aegyptiaca* is an evergreen species, keeping its greenery throughout the year. However, in the time interval from February to June, the foliage of this species experiences an exponential development in the number of leaves. The average number of flowers peaks in March in the study area. Under normal conditions, i.e., without human disturbance, *B. aegyptiaca* fructifies between June and September. *Balanites aegyptiaca* fruits are fully ripe and ready to be harvested between February and May (dry season) in dry areas. **Conclusion:** The results of this study will make it possible to improve the production of plant products and to plan the harvesting periods of the various plant products of *B. aegyptiaca* without harming the survival of the species.

Key words: Balanites park, phenology, pollinating agents, fruit maturation, harvesting periods

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Balanites aegyptiaca plays a very important role in the ecosystems and agrosystems of developing countries. Its importance is crucial, particularly in the Sudano-Sahelian zones, where the tree is considered as a source of fuel and human food and a regulating element of agro-climatic conditions[1]. *Balanites aegyptiaca* is a multipurpose tree, widespread in dry tropical Africa[2]. According to Diop *et al.*[3], it is found almost everywhere in Niger and all its parts are fully used in traditional pharmacopoeia. The leaves, flowers and young twigs are prized in cooking[4,5]. The fruit pulp with a bittersweet taste is sucked like candy. Its drupes marketed by women are also macerated in water and replace sugar in porridge. Their almond extract, is an oil for cooking and making soap. The fruits, leaves and twigs are enjoyed by livestock. The strong and resistant wood is a fuel with a high calorific value and is used for fences, in the manufacture of mortars, pestles, Koranic tablets and tool handles[6,7]. Its main value lies in its perfect adaptation to arid ecosystems and a good production of fruits which are consumed especially in times of food shortage and sold in the markets of towns and villages[8]. *Balanites aegyptiaca* is one of the most cherished but unfortunately vulnerable local food species[5,9]. Indeed, all parts of the plant (roots, leaves, fruits, bark, thorns, wood) are used for food, therapeutic, economic or socio-cultural purposes[10,11]. Much in demand, *B. aegyptiaca* is thus subject to permanent anthropogenic pressure to which are added environmental challenges that dangerously threaten its survival. Non sustainable exploitation accentuated by overgrazing, recurrent bush fires and drought, this species is in sharp decline in the region[11]. Today, it is important to promote local forest species of interest for food and traditional pharmacopoeia on local and regional markets in the face of the growing needs resulting from growing demographic pressure, by controlling their phenological cycle to have a better knowledge and possibly a good programming of the harvest periods of the different organs of these species[1]. The phenological cycles of tropical trees are influenced by biotic, climatic and edaphic factors[8,12,13]. Observations made in Burkina Faso, Ghana, Nigeria, Senegal and Cameroon show that the pollination of *Parkia biglobosa* (Jacq.) R. Br. ex G. Don (Fabaceae) is carried out mainly by bats and chimpanzees[14]. Nowadays, it is important to quantify the fruit resource of wild products for the happiness of African populations in general and Cameroon in particular. According to Boubacar *et al.*[2], the fruit production of forest and agroforestry species in Africa is very little known, which could constitute a brake for the valorization of the products of gathering which are additional incomes for African rural populations, even their domestication. It should be noted that *B. aegyptiaca* has a variable phenology depending on the ecological conditions, few flowers visited and fruit production linked to the size of the trunk. To this end, the best knowledge of this species, the development of its different organs and its rational management requires prior knowledge of its pollinating agents and the development phases of the different organs. The present study aims to inventory the pollinating agents and analyse the behaviour of the organs of *B. aegyptiaca* by presenting the phases of leafing, flowering and fruiting to plan the harvest periods of vegetables, fruits and seeds of this fruit plant very important for local residents.

MATERIALS AND METHODS

Study sites: The study was conducted in the Far North Region located in the Sudano-Sahelian Zone of Cameroon from an ecological point of view. The research spanned from March 01 2020 to September 30, 2022. The investigations took place in three divisions (Diamare, Mayo-Danay and Mayo-Kani) and four sub-divisions (Kalfou, Mindif, Moutourwa and Pette) with geographic coordinates 10°30'0.00N and 11°12'0.00N North Latitude and 13°54'0.00 E and 15°18'0.00E East Longitude.

The interest in the choice of study sites was focused on the presence of *B. aegyptiaca* parks, anarchic and illicit exploitation of non-timber forest products (NWFP) of *B. aegyptiaca* and strong demographic pressure in the Far North Region of Cameroon. The study area covers an area of approximately 5,425 km^2 [15,16]. It is characterized by a climatic regime of the Sudano-Sahelian type. Rainfall is the monomodal type with duration and intensity varying on average between 800 and 1000 mm/year[17]. August and September are considered the epicenter of the rainy season due to the heavy rains. Average annual temperature is 28°C. The soil is sandy-clayey and sandy. The plant formation is of the Sudano-Sahelian type characterized by steppe dominated by thorny shrubs and by its extreme fragmentation due to natural conditions and human action. The population of the area was estimated in 2005 at approximately 249,285 inhabitants[18]. The main economic activities carried out are agriculture, trade, livestock and handicrafts.

Characteristic of the study area

Climate: The study area is characterized by a tropical-type climate with Sudano-Sahelian variants in its southwestern part and Sudano-Sahelian variants in its northern part where there are 2 seasons, a short rainy season of 3 to 4 months, running from June to September and a long dry season of 7 to

8 months, running from October to May. The average annual temperature of the Far North Region is 28°C[19]. The average annual rainfall varies from 600 mm in the North to reach 1000 mm in the South[20].

Geo-climatic characteristics: The soil cover of the Sahel is made up of a series of large depressions (synclines) filled with erosion products from various basement cycles since the Precambrian. The strong climatic variations during this period marked the spatial organization of the landscape and soils. This shows the complexity and variability of the Sahelian environment. This means that the Far North Region has two types of soil: Ferruginous and ferralitic resulting from the intensity of leaching affecting this area[21].

This region is characterized by an arid or semi-arid climate, with a strictly unimodal rainfall regime. Climatic parameters are part of the basic criteria for the delimitation of ecological zones in the Sahel and adjacent regions. This zone is linked to the Sahelian climate with sub-desert nuances. A Sudano-Sahelian climate reigns over the plain with five months of rain ranging from May to October[16]. During these months, the vegetation is green[22]. The sub-divisions based on the average annual rainfall are validated by the fact that the reference potential evapotranspiration is quite homogeneous, between 2500 and 3000 mm/year[23,24]. In addition, when the average annual rainfall is low (100-300 mm/year) the occurrence of years for which the volume and distribution of rainfall do not allow annual species to complete their cycle becomes significant[25]. The general aspects of the savannah, agriculture and average annual rainfall of the Sahelian and adjacent zones of the region are as follows:

- **Saharo-Sahelian zone (100-300 mm):** Very sparse shrubby vegetation; no cultivation
- **Sahelian zone (300-500 mm):** There is the predominance of livestock farming, but also the presence of large cereal crops, in particular, millet (between 300 and 500 mm) and a little sorghum and groundnuts
- **Sahelo-Sudanian zone (500-700 mm):** In this zone cereal crops predominate; more sorghum (*Sorghum bicolor*) than millet (*Pennisetum glaucum*); groundnut cultivation is widespread; we also note the presence of cotton; animal population, in particular cattle, is still numerous
- **Sudano-Sahelian (700-900 mm) and Sudanian (900-1200 mm) zone:** Agricultural activities are multiple and varied; cash crops compete with maize and long growing season varieties of sorghum and millet

Temperature is determined by latitude and radiation, but it is also influenced by general atmospheric circulation, altitude, proximity to sea currents, or continentality of the site[23].

The general atmospheric circulation in the Sahel is marked by the seasonal swing of the African monsoon, which results in the South-North-South back and forth of the contact zone between the intertropical air mass (hot and humid) and the Saharan subtropical air mass (hot and extremely dry). The study area has a hydrographic network which is mostly made up of a temporary river commonly called "Mayo" which is observed only during the rainy season. The vegetation period in the Sudano-Sahelian Savannahs is from June to October. During this period, water is available, since the precipitation curve is higher than the evapotranspiration curve[26].

Vegetation: The dominant plant formation in the Far North Region is the wooded savannah. The flora is very diverse in this area. There are mostly species such as *Acacia albida*, *Balanites aegyptiaca*, *Ziziphus mauritiana*, *Tamarindus indica*, *Acacia seyal*, *Khaya senegalensis*, *Dalbergia sissoo*, *Diospyros mespiliformis*, *Anogeissus leiocarpus*, *Daniellia oliveri*, *Phyllanthus muellerianus* and various species of *Ficus*. Some of these essences are mainly used in the traditional pharmacopoeia[27-31]. Of all these species, *Ziziphus mauritiana* is the most widespread and stands out as the most common plant formation in the study area. This vegetation in this area is undergoing severe deterioration following population growth and excessive cutting of firewood and service wood[30-34]. The vegetation is of the Sahelo-Sudanian type on the bottom of the hills and the border plains and Sudano-Sahelian on the heights and plateaus[5,33].

Botanical characteristic and adaptation of *Balanites aegyptiaca*: *Balanites aegyptiaca* is a thorny tree with drooping branches and glaucous green foliage. It is a species that can measure about 12 m in height. The leaves of this tree are divided into two lobes, they are shorter than its spines which measure up to 10 cm long[35,36]. They are arranged in a spiral along the twigs. The flowers of this plant are greenish-yellow which bloom in the axils of the leaves. The flowers develop into ovoid fruits which are yellow when ripe. These fruits are about 4 cm long with edible pulp and contain an almond rich in oil. *Balanites aegyptiaca* is a species of the Sahelian and Sudano-Sahelian Zones[30,37]. Its distribution extends into dry tropical Africa, Arabia and India. Its favourite biotopes are sandy and stony soils.

Like most plants in semi-arid environments, the desert date palm, also called soap tree, has different morphological adaptations to drought[38]. These adaptations are particularly varied here: Pubescence, sclerification, leathery leaves, assimilating chlorophyllian branches reduced to the state of thorns, double root system (an extensive superficial root system that efficiently captures water immediately after precipitation in a radius of about 15 m and a deep root system that draws water from soil reserves up to about 5 m). It is because of this device that *B. aegyptiaca* has a great resistance to droughts. However, the desert date palm lacks a photosynthetic metabolism adapted to dry environments of the C4 or CAM type, but an ordinary C3 metabolism[30,31].

Methods

Inventory of flower visiting agents: Agents visiting *B. aegyptiaca* flowers were followed in the parks of the four Arrondissements. The observation took place during the flowering period of *B. aegyptiaca*, from February to July. The method used consists of a manual and instantaneous capture of the agents visiting the flowers using a sweep net. Data collection took place in four phases, two daytime phases and two night-time phases. The daytime collection of flower visitors is carried out from 8 am to 10 am and from 4 pm to 6 pm, i.e. two observations per day for 15 days. The nocturnal observations carried out from 8 pm to 10 pm and from 4 am to 6 am are carried out in the *B. aegyptiaca* parks. For each of these observations, all the agents captured were immediately placed in transparent boxes pierced with several holes for living insects and in a jar of ethanol concentrated at 70°C for insects that have died from stress, as done by Olsson *et al.*[1] and Tope *et al.*[39]. The boxes are labelled for identification by expert entomologists or in the laboratory. The observation was carried out in the morning and the evening during an ambient temperature favourable for the movement of insects. Assuming that environmental factors (microclimate or sun intensity) may influence the distribution and activity of visiting agents. According to Olsson *et al.*[1], the type of trap can significantly influence the number and nature of insects captured. This method aims to give an idea of the main potential pollinating agents of *B. aegyptiaca*. The knowledge of these visiting agents would be necessary for the improvement of the productivity of *B. aegyptiaca*.

Phenological evaluation of *B. aegyptiaca*: The phenological characterization (leafing, flowering and fruiting) by division, was carried out from March 01, 2020 to September 30, 2022, based on the methods described by Olsson *et al.*[1] and Abdoulaye *et al.*[11]. It is called leafing the period from the formation of leaf buds to the total maturation of the leaves (change of colour or fall of the leaves). It is marked by a few key stages such as full leafing, which corresponds to a time when *B. aegyptiaca* individuals bear more than 60% young green leaves.

Flowering extends from the formation of flower buds until the end of flowering, which is manifested by the withering and browning of the flowers. It is marked by a few key stages such as full flowering, which corresponds to a time when the individuals bear more than 60% of the flowers. In each sub-division, flowers are observed on the four sides of the tree. The flowers of *B. aegyptiaca* are observed with the naked eye and their dimensions were measured (length and width) and the number of flowers per inflorescence from the beginning to the end of the observation.

Fruiting extends from the onset of fruit formation until fruit ripening. It is reported that fruit ripening is when more than 60% of a tree's fruit ripens. The evaluation of the fruit production of *B. aegyptiaca* was carried out in 2022 and involved a sample of 40 individuals. These individuals come from the 50 trees previously selected for the experiment. Fruit production is determined based on the method used by Johnson *et al.*[42]. The fruits are counted on numbered individuals, with the naked eye or using a pair of binoculars. The number of fruit appearances is counted over time. The fruits are measured in length, width and thickness from the beginning of the appearance until the end of the observation.

Per division, the observations concerned 10 whole individuals of *B. aegyptiaca* without anthropogenic traces, therefore likely to produce plant organs. That is 40 individuals in the four sub-divisions. They are performed in the morning with the naked eye (visual and direct observation) and sometimes using binoculars for organs located in the treetops[14]. Given the remoteness of the four sub-divisions, each site was visited once per week (07 days), for 6 months, i.e., a total of 960 observations in all of the four sub-divisions studied.

Data processing and analysis: The phenological data are presented in the form of graphs. The absolute frequency of flower visitor agents is calculated from the number of agents collected per order and according to the formula:

$$f = \frac{n}{N} \times 100$$

Where:

f = Percentage of visitor agents of an order
n = Number of individuals of an order
N = Total number of visiting agents collected

These agents were identified at the level of taxonomic order using identification keys according to the method presented by Fougeroux *et al*.[40], expert entomologists or even in the laboratory. The distribution of plant organs on individuals and their correlation were carried out using the principal component analysis of variables. Graphs and various tests were carried out using EXCEL 2016 spreadsheet and XLSTAT 2007 software.

RESULTS

Diversity of potential pollinating agents of *B. aegyptiaca*: The results of the observation show that *B. aegyptiaca* is visited by several pollinating agents. A total of 87 visitor agents were caught on 40 feet of *B. aegyptiaca* in the four sub-divisions. Potential visitor agents that pollinate *B. aegyptiaca* flowers captured in the four divisions are divided into seven different orders (Fig. 1), which are: Hymenoptera (31%); Diptera (26%); Lepidoptera (24%); Hemiptera (11%), Dictyoptera, Orthoptera each represents 3% and Coleoptera account for 2%. Hymenoptera, represented by bees (*Apis mellifera*) are the most captured (31%) on individuals of *B. aegyptiaca*. During the observation phase, Balanites pollens were observed several times on the body of the bees, some of which are visible on the flowers. Their high percentage on *B. aegyptiaca* individuals and their long presence on the flowers of this species allow them to be considered as main and constant visitors. The Diptera captured on flowers are made up mainly of flies come in second place with (26%). Their high percentage on the plants of *B. aegyptiaca* makes it possible to consider them as frequent visitors to the flowers of this species. The diptera observed are mostly small flies, the majority of which are captured almost every day of the experiment, especially during the full bloom period. This leads to the assumption that the order Diptera visits flowers at a time when the amount of food is abundant. In the 11% of Hemiptera captured, the majority belong to the family Formicidae (ants). Except that, insects were not observed carry pollens on the flowers. On the other hand, in the field, many bees (*Apis mellifera*) have been observed flying away with the pollen from the flowers of *B. aegyptiaca*. For the 24% of captured Lepidoptera (butterflies), the vast majority were captured in the evening, which explains the nocturnal activities of certain insects on the flowers of *B. aegyptiaca*. Praying mantises (*Manta* spp.), were also captured on the feet of *B. aegyptiaca*. Several termites (Isoptera) have been observed on *B. aegyptiaca* but have not been considered as potential pollinators of *B. aegyptiaca* flowers. Among all insects, bees are considered the main potential pollinators of plant species (Fig. 2a-d).

Evaluation of the foliage of *B. aegyptiaca* in the four sub-divisions: Being an evergreen plant, *B. aegyptiaca* keeps its leaves throughout the year. However, the plant can lose its leaves following anthropogenic disturbances (bush fires, cuts, etc.) and proceed to renewal by regeneration. This renewal is very important for the local populations who are in search of the young leaves which are consumed as vegetables. However, in a natural way, the number of leaves varies according to the month and its peak is reached in the month of April in three sub-divisions (Kalfou, Mindif and Moutourwa) and for Pette sub-division, the peak is reached in the month of May (Fig. 3). In Kalfou sub-division, the number of leaves varies from 1500 leaves in January to 850 leaves in December. In this sub-division, the peak is reached with a number of 4350 leaves in April. The number of leaves remained high in May (3450 leaves) before plummeting in June (2500 leaves). In Mindif sub-division, the number of leaves ranges from 1950 leaves in January to 1200 leaves in December. The highest point is reached at 4800 leaves in this locality. The month of April with a number of leaves of 3700. In Moutourwa, these values vary from 2400 leaves in January to 1590 leaves in December. The peak number of leaves reached 5150 in April in this sub-division. March comes next with a leaf count of 4750. For Pette sub-division, the number of leaves varies from 1450 leaves in January to 580 leaves in December. In this sub-division, the highest number of leaves is obtained in May with a number of leaves of 4500. These results show that in all the sub-divisions studied, the number of leaves is higher from April to May, with an increase that begins in February, which is the period characterized by a favourable average temperature for species in the Sahel. This indicates the time of existence of young leaves of *B. aegyptiaca*, which are important for local populations. The Analysis of Variance (ANOVA) shows a highly significant difference between the months of all the sub-divisions ($p = 0.000<0.05$). Between sub-divisions, analysis of variance does not indicate any significant difference ($p = 0.36>0.05$). These results tell us the stages of leaf development of *B. aegyptiaca*. The most important period for populations is when buds appear (March-April). This is the right time for harvesting young leaves for women who are the main harvesters of *B. aegyptiaca* leaves. The leaves of *B. aegyptiaca* are used as vegetables in the Far North of Cameroon.

Evaluation of *B. aegyptiaca* flowers in the four sub-divisions: Figure 4 shows the evolution of the number of *B. aegyptiaca* flowers per month in the Sudano-Sahelian Zone of Cameroon. For this specific species, the average number of flowers reaches its peak in March in all the sub-divisions of the study area. In Kalfou sub-division, the number of flowers varies

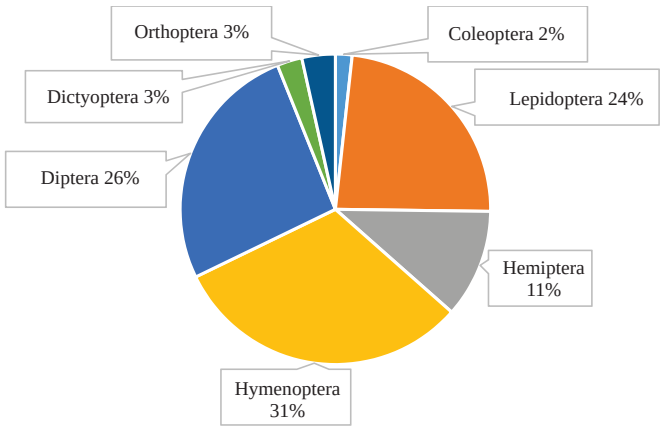

Fig. 1: Percentage by taxonomic order of visiting agents of *B. aegyptiaca*

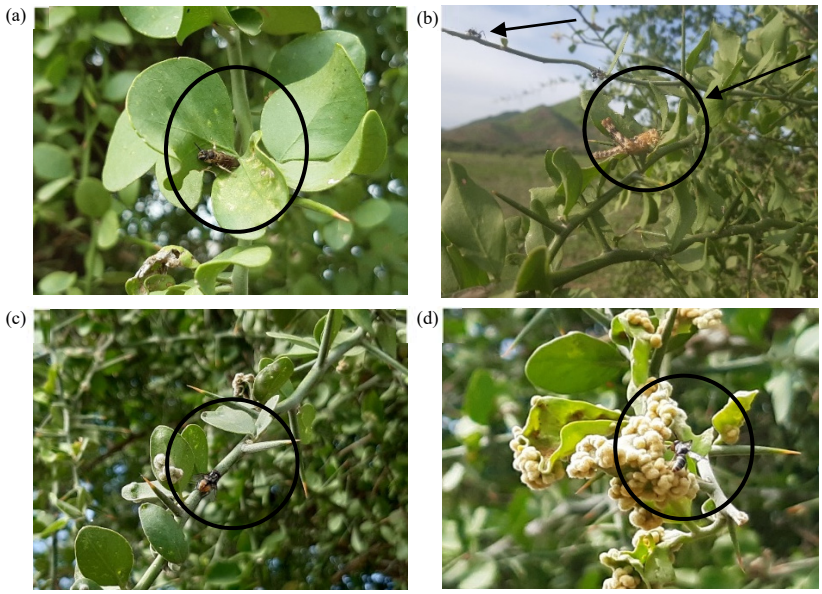

Fig. 2(a-d): Images of some pollinating agents on *B. aegyptiaca* individuals studied, (a) Bee (Hymenoptera), (b) Grasshopper (Orthoptera), (c) Fly (Diptera) and (d) Wasp (Hymenoptera)

from 28 flowers in February to 2160 flowers in May. The peak of flowers in this locality is reached in May with a number of 2160 flowers. The number of flowers remained high in April (1055 flowers) before plummeting in June (954 flowers). For Mindif sub-division, the number of flowers varies from 40 flowers in February to 1880 flowers in May. The highest number of flowers is recorded at 1880 flowers in May. The month of April comes next with 875 flowers. In Moutourwa sub-division, the values vary from 32 flowers in July to 2590 leaves in May. The peak number of flowers is reached at 2590 in May in this sub-division. The month of April comes next with 1680 flowers. For the locality of Pette, the number of flowers varies from 16 flowers in July to 1658 flowers in May. In this sub-division, the highest number of flowers is obtained in May with a number of flowers of 1658. It is followed by April with a number of flowers of 715. These results show that in all the sub-divisions studied, the number of flowers is higher in May, with an increase that begins in April, which is the period characterized by sunshine favourable to the development of flowers. Flowering of *B. aegyptiaca* takes place between April and May throughout the study area. Through these results, we find that the leaves and flowers of *B. aegyptiaca* evolve simultaneously. These phenological phenomena are preparations for fruiting. It should be noted that according to the number of flowers, the Analysis of Variance (ANOVA) specifies a highly significant difference between the sub-divisions and between the months ($p = 0.000<0.05$).

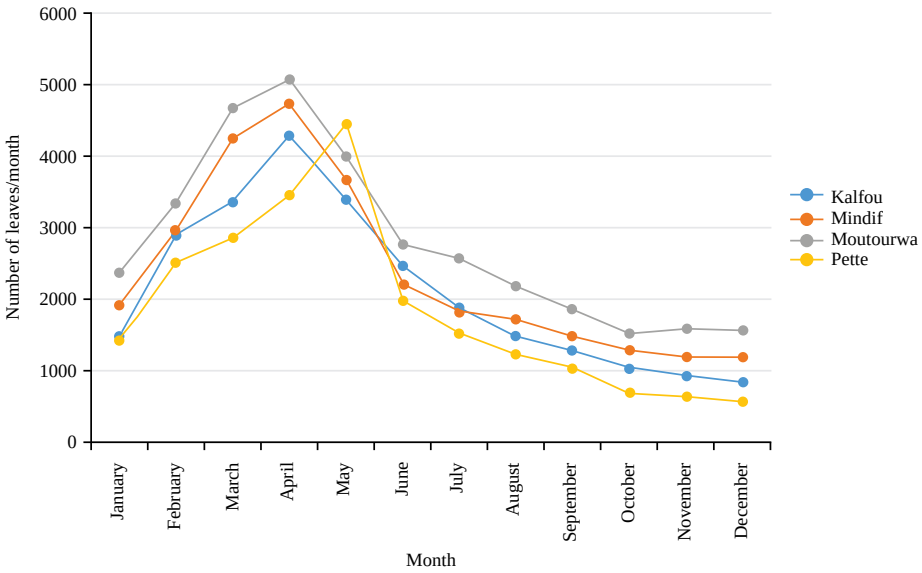

Fig. 3: Leaf growth curve in the four sub-divisions

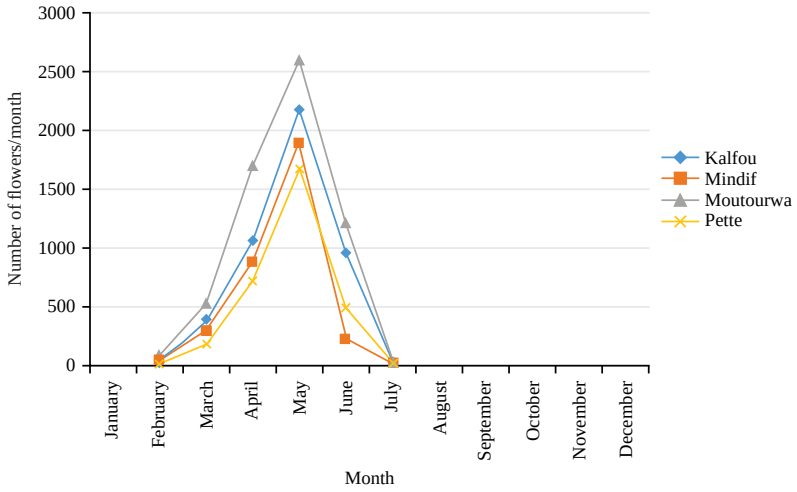

Fig. 4: Evolution of flowering in the four sub-divisions

Evaluation of fructification of *B. aegyptiaca* in the four sub-divisions: The fruits of *B. aegyptiaca* are the most important organs with various virtues (food, medicine). This essence produces fruits in large quantities which are used in different fields. From the fruits of *B. aegyptiaca*, seeds are extracted which are used in different natures (grilled for consumption, oil production). Under normal conditions, i.e., without human disturbance, the number and size of fruits of *B. aegyptiaca* varies with time. *B. aegyptiaca* fruits between June and September (Fig. 5). In the Sahelian Zone of Cameroon, this species bears fruit from June to January with a peak in August. In Kalfou sub-division, the number of fruits varies from 44 fruits in June to 2560 fruits in August. In this sub-division, the peak of the number of fruits is reached with a number of 2560 fruits in August. The number of fruits remains close to the peak in September (2500 fruits). In Mindif sub-division, the number of fruits ranges from 53 fruits in June to 2210 fruits in August. The peak of the number of fruits is reached at 2210 fruits in August in this sub-division. The month of September follows with a number of fruits of 2110. Moutourwa is the sub-division which has presented the highest values. These values vary from 85 fruits in June to 3845 fruits in August. The peak number of fruits in this sub-division is reached at 3845 in August. The month of

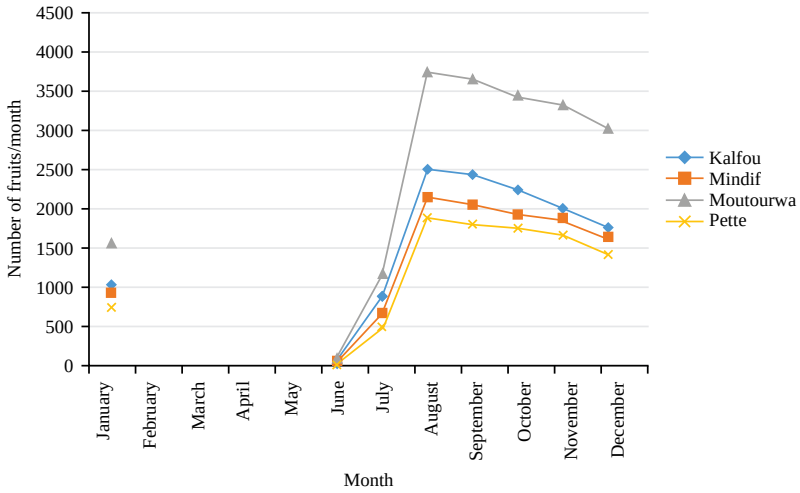

Fig. 5: Fruit growth curve in the four sub-divisions

September comes next with a number of fruits of 3750. Pette sub-division is the locality which presents the lowest values. The number of fruits varies from 25 in June to 1930 fruits in August. In this sub-division, the highest number of fruits is observed in August with a number of fruits of 1930. It is followed by September with a number of fruits of 1840. The Pette sub-division presents the lowest number of fruits with a peak of 1930 fruits. The low number of fruits recorded in this sub-division is probably linked to the early picking of fruits from the trees by cattle because Pette is one of the places where the Mbororo are the most numerous and most frequent. Fruiting of *B. aegyptiaca* covers 3 months in all sub-divisions. The phenomenon thus observed at all the sites is therefore not natural, but linked to the effect of picking by human beings. According to study observations, the fruits ripen around September. These results allow us to indicate the reasonable periods of maturation and ripening of the fruits of *B. aegyptiaca*. This allows operators to control when to harvest fruit for various purposes. It should be noted that the analysis of variance shows a highly significant difference between the weeks of reading the parameters ($p = 0.000<0.05$). Between the sub-divisions, ANOVA indicates no significant difference ($p = 0.28>0.05$). The results of this study showed the different stages of fruiting of *B. aegyptiaca*. The most important period for farmers is the ripening period (September). This period allows local populations to know the right time to harvest the fruits of *B. aegyptiaca* for good exploitation.

Principal component analysis of the different variables studied: Figure 6a presents the correlations between the different parameters studied (number of leaves, number of flowers and number of fruits). The F1 axis, which contributes 92.22%, explains the distribution of plant organs. This axis is correlated with the parameters studied, in particular with the number of flowers and the number of fruits, which present a high density of plant organs of the order of 17121 flowers and 55167 fruits. The three variables respectively show a positive and highly significant correlation ($p<0.001$) with respective correlation coefficients (r) of the order of 0.928; 0.959 and 0.993. On the other hand, the correlations between the number of leaves and the number of flowers is not significant ($p>0.05$), with correlation coefficients of 0.928 and 0.959, respectively. The number of leaves recorded (111130) is greater than that of flowers (17121) and the number of fruits, which is 55167 fruits. It should be noted that *B. aegyptiaca* is an evergreen species, it is for this reason that the number of leaves remains high in relation to the number of flowers and the number of fruits.

Figure 6b shows the distribution of the three plant organs (number of leaves, number of flowers and number of fruits). In the four sub-divisions, the plant organs are disseminated in a variable way (Fig. 6b). The F1 axis, which contributes 99.29%, divides the plant organs into two groups. The number of flowers and the number of fruits on the left and the number of leaves. It is negatively and significantly correlated with the number of flowers and the number of fruits. For the number of leaves, it is positively correlated and highly significant. The contribution of the F2 axis is very low, 0.71%. It separates the number of fruits above the number of flowers and leaves. The F1 axis therefore separates the organs with low density (number of fruits and number of flowers) with the number of flowers which has a very high density.

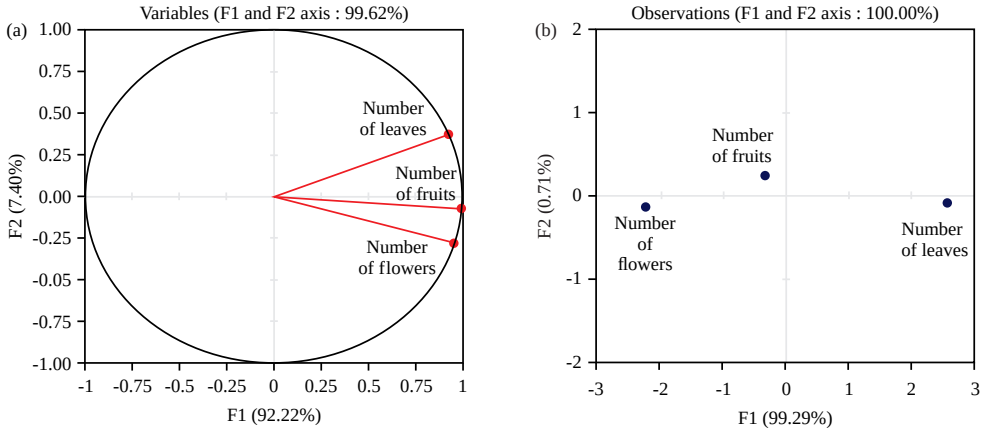

Fig. 6(a-b): (a) Correlation and (b) Dispersion between the number of leaf, flower and fruit

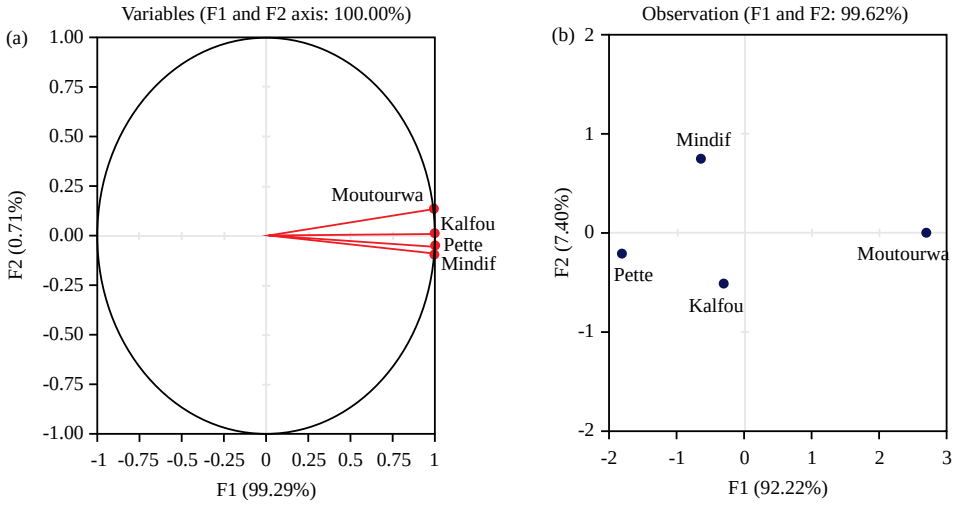

Fig. 7(a-b): (a) Correlation and (b) Dispersion of plant organs between the sub-divisions

Principal component analysis of the different sub-divisions: Figure 7a presents the correlation between the four sub-divisions (Kalfou, Mindif, Moutourwa and Pette). This correlation is positive and significant between the four sub-divisions, with the correlation coefficient of 0.995 between Kalfou and Mindif, 0.992 between Kalfou and Moutourwa, 0.975 between Mindif and Moutourwa, 0.998 between Kalfou and Pette, 0.999 between Mindif and Pette and 0.982 between Moutourwa and Pette. The low significance between Mindif and the other three sub-divisions is due to the infertility of the soil in Pette sub-division and the fertility of the soil is necessary for the development and growth of plant organs in other sub-divisions.

Across all four sub-divisions, plant organs are distributed in a variable manner (Fig. 7b). The Moutourwa sub-division is the most represented in terms of density of plant organs. This sub-division is separated from the others by the F1 axis whose contribution is 92.22%. Kalfou and Mindif sub-divisions are moderately represented. Pette sub-division, located to the far left of the F1 axis, is the weakest.

Principal component analysis of the different sub-divisions: Figure 7a presents the correlation between the four sub-divisions (Kalfou, Mindif, Moutourwa and Pette). This correlation is positive and significant between the four sub-divisions, with the correlation coefficient of 0.995 between Kalfou and Mindif, 0.992 between Kalfou and Moutourwa, 0.975 between Mindif and Moutourwa, 0.998 between Kalfou and Pette, 0.999 between Mindif and Pette and 0.982 between Moutourwa and Pette. The low significance between Mindif and the other three sub-divisions is due to the infertility of the soil in Pette sub-division and the

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DISCUSSION

The flowers of *B. aegyptiaca* are intensely visited by several insects, the most numerous of which are Hymenoptera, Diptera, Lepidoptera and Hemiptera respectively. These insects frequent the flowers of *B. aegyptiaca* much more during the day, more precisely in the morning. A small number of much larger insects of the order Hemiptera usually make nocturnal visits to the feet of *B. aegyptiaca*. The presence of diurnal but also nocturnal visitors suggests that *B. aegyptiaca* flowers open during the day but also at night. These results confirmed the work of Olsson *et al.*[1] who reported that the flowers of *Detarium microcarpum* open as much during the day as at night and are visited by insects of the same order. Knowledge of *B. aegyptiaca* visitor agents is very important for controlling the pollination of this species in order to increase fruit production so that local communities derive socio-economic and cultural benefits from *B. aegyptiaca* parks[41]. The study results show that bees (Hymenoptera) are the most numerous in the flowers of *B. aegyptiaca*. The strong presence of bees observed in the field on the flowers of *B. aegyptiaca* indicates a revitalization of beekeeping activities to make the production of other plants profitable through their pollination. These observations are contrary to those of Johnson *et al.*[42] and those of Aichetou *et al.*[43] who presented a strong pollination of African plants by butterflies (Lepidoptera). This difference in visitor orders would be due to the plant species studied. These authors conducted their study on *Prosopis africana* while our study was focused on *B. aegyptiaca*. Indeed, each plant species has odors and colors of flowers specific to insect taxa. These results suggested that *Prosopis africana* and *B. aegyptiaca* have different odors to attract visiting agents.

The leaves of *B. aegyptiaca* are small in size in the Sudano-Sahelian Zone of Cameroon. This species is an evergreen species, keeping its greenery throughout the year. However, in the time interval from February to June, it is noticed that the foliage of *B. aegyptiaca* experiences an exponential development in a number of leaves. This increase in the number of leaves is linked to environmental conditions favourable to the development and growth of species in the Sahelian zone, which includes *B. aegyptiaca*. This is a period that corresponds to the beginning of the rainy season. Current study results confirmed those of Habou *et al.*[44], who found in their study that the leafing time of *B. aegyptiaca* is between February and March. On the other hand, the results of our study are different from those of Tsufac *et al.*[45], which showed that leafing of *B. aegyptiaca* begins in January. This difference would be due to the ecological conditions of the study area. These authors worked in the Guinean zone with favourable climatic conditions for plant development, while current study was conducted in the Sahelian zone with different climatic conditions. Indeed, climatic and ecological conditions influence the different phenological phases of plant species. The results of this study present the stages of leaf development of *B. aegyptiaca*. The most important period is when the buds appear (March-April). This indicates the right time to harvest young leaves by women who are the main harvesters of *B. aegyptiaca* leaves. The leaves of *B. aegyptiaca* are used in the form of vegetables in the Far North of Cameroon. Identical results were obtained Abdoulaye *et al.*[11] by studying the socioeconomic and cultural utilities of *B. aegyptiaca* (L.) Del. (family Zygophyllaceae) in local populations of the Ouaddai Region in Chad.

Flowering is a phenological phase that precedes fruiting. For this specific species, the average number of flowers peaks in March in the study area. In Kalfou sub-division, the number of flowers varies from 28 flowers in February to 2160 flowers in May. The peak of flowers in this locality is reached in May with a number of 2160 flowers. These results show that throughout the study area, the number of flowers is higher in May, with an increase that begins in April, which is the period characterized by sunshine favourable to the development of flowers. Flowering of *B. aegyptiaca* takes place between April and May throughout the study area. These results, showed that the leaves and flowers of *B. aegyptiaca* evolve simultaneously. These phenological phenomena are preparations for fruiting. These results were in agreement with those of Diop *et al.*[3] which indicated the same flowering period of *B. aegyptiaca*. According to Olsson *et al.*[1], high temperature and rainfall positively influence the total blooming of flowers, which confirmed the results of current work. Other authors such as Murali and Sukumar[46] explain that the flowering of savannah species in the rainy season by the inhibition of floral initiation is due to water stress in the dry season. Irregularities in the fruiting of savannah species are confirmed by Souleymane *et al.*[47]. The different temporal and spatial variations for the fruiting phase in tropical trees are

reported by other phenological studies[1,48,49]. Knowledge of temporal irregularities in fruiting is very important for the harvesting of *B. aegyptiaca* fruits by farmers. This study field observations show that *B. aegyptiaca* is a very productive species in edible fruits. The combination of these results and those of the ethnobotanical survey shows that the fruits of this species are one of the most consumed and marketed products in the Sudano-Sahelian Zone of Cameroon, more precisely in the northern part. This demonstrates the need for valorisation of *B. aegyptiaca* which will allow an improvement of the living conditions of local farmers through the marketing of these products. It appears from our study that the maturity of the fruits is earlier in Pette sub-division in the Sudano-Sahelian zone. These results confirmed those of Tchiagam *et al.*[50], who demonstrated that most fruits of savannah species mature early due to climatic and ecological conditions such as drought and anthropogenic actions. Current study observations also showed that the fresh fruits of *B. aegyptiaca* are relatively fleshy drupes, unlike the majority of other savannah species fruiting in the dry season and the maturation of fruits of *B. aegyptiaca* is short. This short fruit maturation is observed in most savannah species[34]. Conservation trials of seeds of local forest species, carried out in the Sudano-Sahelian zone of Cameroon according to our surveys, indicate that the seeds of *B. aegyptiaca* can be well conserved at room temperature, in jute bags for several years, but their germination often requires pre-treatment to break dormancy. The study results on the fruiting phase show us the different stages of maturation of *B. aegyptiaca* fruits. The most important period for farmers is the ripening period (September). This period allows local populations to know the right time to collect *B. aegyptiaca* fruits for proper exploitation.

CONCLUSION

The phenological study of *B. aegyptiaca* has made it possible to identify the various potential visitor agents that pollinate flowers and the phenological phases of this species. Visiting agents belonging to seven orders of insects (Hymenoptera, Diptera, Lepidoptera, Hemiptera, Dictyoptera, Orthoptera and Coleoptera) were inventoried. The most numerous of these insects belong to the order Hymenoptera. The results of the phenological study of *B. aegyptiaca* revealed the periods of production of the different organs and the phases of maturation of these organs. Flowers specifically appear between February and June. Fruiting of *B. aegyptiaca* begins in June and ends around September. The fruits are completely ripe and ready to be harvested between February and May (dry season) in the dry zone and between April and June (end of the dry season and beginning of the rainy season) in the humid zone. The variability of the phenological phases of *B. aegyptiaca* is attributable to climatic conditions such as soil humidity and rainfall. Further in-depth studies on the impact of edaphic and climatic conditions on the phenology of the species are in prospects.

SIGNIFICANCE STATEMENT

Fruits, leaves, wood and processed products of *Balanites aegyptiaca* play a major role against famine in Sahelian zones already overwhelmed by demographic explosions and droughts. However, *B. aegyptiaca* being a valuable resource is faced with abusive exploitations beyond its natural regenerative capacity. This study seeks to provide appropriate information on technics that permits a sustainable exploitation of this plant.

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