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Phenology and Nutritional Value of *Piliostigma thonningii* Pods (Sanumach Mile Redh): A Sahelian Resource for Livestock Farming in Burkina Faso

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Abstract

One of the major challenges facing livestock farming in Burkina Faso is to optimise the production of animal feed resources. Feed resources are insufficient and poor, limiting livestock productivity. The aim of the study was to help improve the availability of animal feed to increase livestock production by using *Piliostigma thonningii* pods. Firstly, it consisted of phenological monitoring of *Piliostigma thonningii* plants at four (04) different study sites, namely Dafinso (site 1), Guena (site 2), Nasso (site 3) and Tondogosso (site 4), followed by an estimate of fruit production from pods per plant and bromatological analyses. Monitoring consisted of visual observation of flowering and fruiting of ten (10) individuals per site at 15-day intervals for 07 months. To assess fruit production, all pods per plant were harvested and the diameter at breast height of each fruiting plant was measured. The chemical composition was determined using near-infrared spectroscopy. Observations show that the flowering phase begins in July and ends in October, while fruiting begins in late August/early September and ends in early December. However, the minimum and maximum lengths were 2.87 ± 0.96 cm and 21.61 ± 4.06 cm, respectively, and the maximum diameters were 0.50 ± 0.24 cm and 5.00 ± 0.60 cm, respectively. PCA analysis showed a strong positive correlation between DHP and pod quantity (r = 0.72). Production was estimated at an average of 6.62 ± 3 kg of dry pods per tree, with 40 flowering trees and 62.5% fruiting trees compared with 37.5% non-fruiting trees. Chemical analysis of the *P. thonningii* pods revealed high levels of MAT (5.95% - 12.88% MS) and lignin (17.06% - 20.15% MS). Mastery of the phenological cycle could be of great use to livestock farmers looking for resilient solutions to their livestock feed requirements.

Subject Areas

Zoology

Keywords

Piliostigma thonningii Pods, Animal Nutrition, Phenological Cycle, Production, Burkina Faso

1. Introduction

In the countries of the Sahel, the population is predominantly rural and closely dependent on agriculture and livestock farming [1]. Livestock farming accounts for up to 40% of agricultural Gross Domestic Product (GDP). It is one of the fastest-growing economic sectors in developing countries [2]. In Burkina Faso, the livestock sub-sector occupies a prominent place in the country's economic growth. With approximately 40% of agricultural value added and 30% of export earnings [3], it is characterized by the existence of a numerically large and diversified livestock population and it contributes significantly to the fight against poverty, food and nutritional security and job creation [4]. Despite this importance, livestock farming continues to face the insufficiency and low nutritional value of annual herbaceous fodder in the dry season [5]. One of these measures is the use of aerial grazing during the dry season [6]. Some researchers in Burkina Faso and elsewhere have been interested in the use of woody fodder in animal feed [5] [7] and [8]. They have focused a lot on the identification of woody fodder and the determination of their nutritional values. They constitute a food supplement both in terms of quality and quantity, thus making it possible to fill seasonal fodder deficits and maintain livestock [5] [9]. *Piliostigma thonningii* is one of the fodder species whose leaf biomass, particularly its "pod" fruits, is a preferred food resource for domestic ruminants [10] [11]. Its use is important to solve the problem of feeding animals, especially in the dry season. For optimum use of *Piliostigma thonningii*, it is necessary to know its phenological cycle in order to plan better. However, mastery of the phenology of these plants could eventually enable fruit production to be assessed qualitatively and quantitatively.

This is the background to our study on "Phenological monitoring and evaluation of *Piliostigma thonningii* pod production in the Sudanian zone of Burkina Faso for use in animal feed". The general aim is to help improve the availability of animal feed and increase animal productivity by using *Piliostigma thonningii* pods. More specifically, the aim was to:

—Determine the duration of various phenological stages, from the appearance of flower buds to the harvesting of *Piliostigma thonningii* pods;

—Analyse the chemical composition according to pod development stages;
—Determine the optimum period for using *Piliostigma thonningii* pods for livestock.

2. Presentation of the Study Area

This study was carried out in western Burkina Faso in the provinces of Houet and Kénédougou in the Hauts-Bassins region. A total of 4 sites were chosen for data collection (**Figure 1**), including three sites (Dafinso, Nasso and Tondogosso) in the province of Houet and one site (Guena) in the province of Kénédougou. The Houet and Kénédougou provinces are located at 11˚20'00" North, 4˚15'00" West and 11˚25'00" North, 5˚00'00" West respectively. They are bordered to the north by the Boucle du Mouhoun region; to the south by the Republic of Ivory Coast; to the east by the Sud-Ouest region and to the west by Mali [12]. The soil cover of the region is quite varied; it includes tropical ferruginous soils with little leaching, hydromorphic soils, tropical ferruginous soils with little leaching on sandy materials, sandy-clayey soils, and sandy soils [13]. Indeed, in Kénédougou, the soils are mostly deep (depth greater than 100 cm) with an average drainage capacity. They are rich in minerals and poor in organic matter. They are suitable for growing cash crops such as sesame, cotton and peanuts. On the other hand, in Houet, the soils are mostly hydromorphic on old hardpan and favorable to agriculture [12]. The climate is tropical with two seasons, namely the dry season from November to April and the rainy season from May to October, with average annual rainfall between 900 and 1200 mm [14]. The region is very rich in plant resources, especially fodder ligneous plants. In fact, a study carried out by [15] on *P. thonningii* in the Houet province showed that pods are fairly available. Their availability, therefore, depends on the production period, which is seasonal. The same study also showed that pods are used in various forms in animal feed, and farmers have a good knowledge of the species.

3. Materials and Methods

3.1. Plant Material

The plant material used was forty (40) *P. thonningii* plants consisting of trees and shrubs of varying ages within the population at the various study sites.

Technical equipment

The various items of technical equipment used to carry out the fieldwork were as follows:

- A 150 cm metric tape for measuring the length and diameter of the pods;
- A box of paint for identifying the different stems and twigs;
- A pair of chisels for collecting the pods and numbering the different stems;
- A felt-tip pen for numbering the different pods;
- Plastic bags for packaging the collected pods;
- Nan electronic load cell with a capacity of 50 kg and a sensitivity of ±10 g for weighing the collected pods.

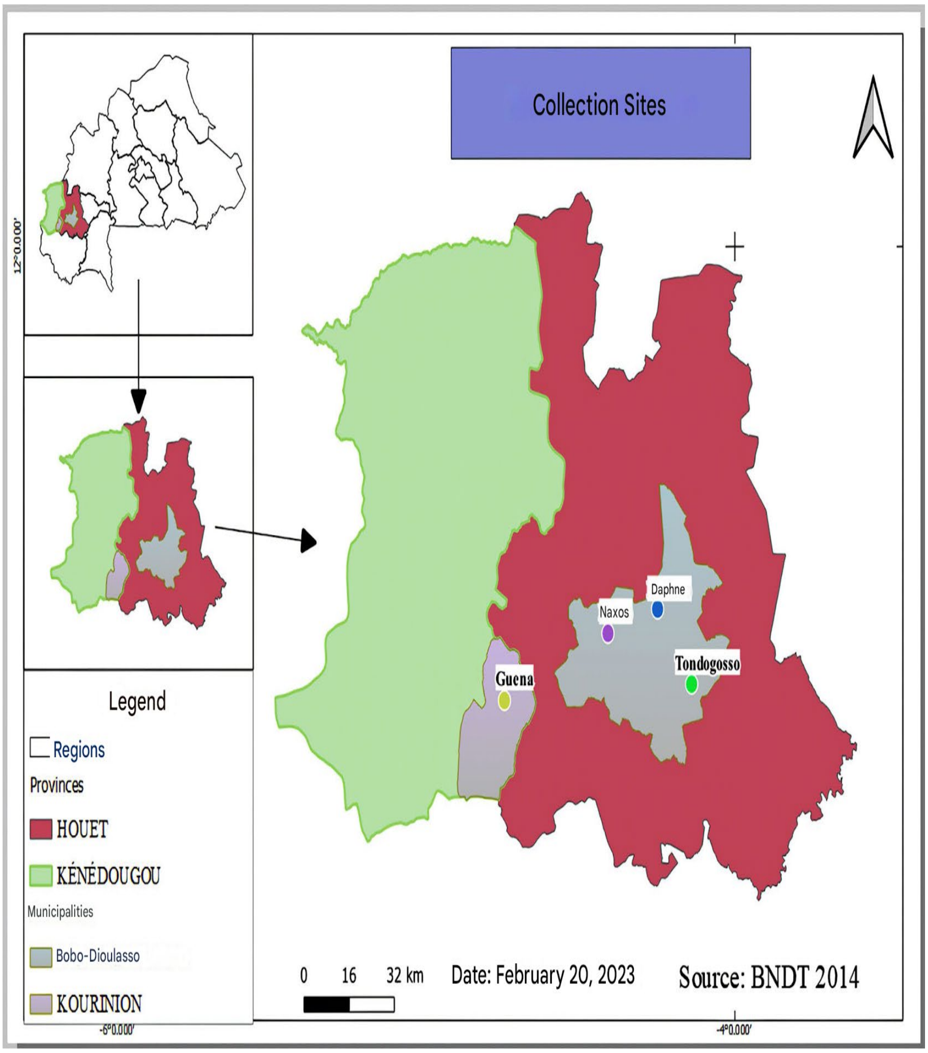

Figure 1. Map showing location of collection sites.

3.2. Study Methods

3.2.1. Flowering and Fruiting Phenology

1) Qualitative Measurements

A comprehensive inventory was initiated to determine the species for phenological monitoring after site identification to determine stand structure. For the inventory, woody plants were recorded by direct counting on quarter-hectare square plots. This area covers the minimum area defined for the woody layer in savannah zones [16]. A total of four plots were systematically inventoried. For each *Piliostigma thonningii* individual, the following parameters were measured:

- Stump number;
- Number of stems per individual;
- Basal circumference (using a 1m tape measure);
- Circumference at breast height (1.30 cm);
- Total height (using a graduated pole). For other species, only the scientific names, height and number of individuals were recorded.

In order to study the availability period of *Piliostigma thonningii*, its phenology was monitored by qualitative observations using the reference stages described by [17] and [18]. Observations were made with the naked eye, regularly and every 15 days on the same plants for 07 months, between July 2022 and January 2023 [19] [20]. Monitoring was carried out at 4 different study sites, namely Dafinso, Guena, Nasso and Tondogosso. Ten individuals were randomly selected per site, marked with paint and numbered from 1 to 10 at each site. The samples studied were individuals of varying ages, with a total of 40 plants observed. Two phases were observed: flowering (f) and fruiting (F). Each phase is characterised by three phenological stages (**Table 1**). The fruiting plants were identified and five pods were randomly selected, numbered from 1 to 5 for length and diameter measurements per site (**Photo 1**).

Table 1. Phenophases, stages and corresponding characteristics recognised for phenological monitoring of the species.

Phenophases	Stages	Characteristics
	f1	Beginning of flowering with unfolding of floral buds
Flowering (f)	f2	Full flowering
	f3	End of flowering, fall of floral parts
	F1	Beginning of fructification
Fructification (F)	F2	Full fructification
	F3	End of fructification with ripening of fruit and their fall

Photo 1. *Piliostigma thonningii* pods numbered 1 to 5 (photo by Sawadogo, 2022).

2) Quantitative measurements

Quantitative measurements can also be used to study the phenological cycle, since any individual can have several stages with cumulative frequencies of 100%. In this case, the phenological spectrum is established by calculating, for each observation date, the frequencies within the population of individuals in the flowering (f%) and fruiting (F%) phases [21]. The relationship is as follows:

$$P(\%) = \frac{ni}{N} * 100$$

P (%): percentage of individuals at the site present at the various flowering or fruiting phases;

ni: number of individuals at a given phenological stage;

N: total number of individuals (population size).

A phase of development is considered to have been reached for an individual when it presents one of the 4 following stages: 1, 2, 3 and 4 (**Table 2**) [21]. It is on this basis that the phenological spectrum of the plant species (*P. thonningii*) has been established. The parameters examined are the percentages of flowering and fruiting individuals.

Table 2. Rating of phenological stages corresponding to frequencies.

Phenophases	Stages	Parameters	Percentage (%)
Flowering	1	None	0
	2	Low	1 - 20
	3	Medium	20 - 60
	4	Intense	>60
Fructification	1	None	0
	2	Low	1 - 20
	3	Medium	20 - 60
	4	Intense	>60

3.2.2. Bromatological Analysis of *P. thonningii* Pods

In addition to observations on the phenology of *P. thonningii*, samples of pods were collected at the different stages of fruiting development of the species. Samples were collected every 15 days from the start of the fruit development phase until it reached its maximum size and the pods began to dry. These samples were dried in the shade and subjected to bromatological analysis to monitor changes in chemical composition. This made it possible to pinpoint the most suitable period for harvesting and storing these pods. The samples (dried pods) were ground to 1mm using an electric grinder (photo) before being subjected to an analysis of their chemical composition. The technology used was Near Infrared Spectroscopy (NIRS). Near Infrared Spectroscopy (NIRS) calibration is based on the establishment of multivariate regression models that correlate the measured spectra with reference analytical values, thus allowing the chemical composition of unknown samples to be accurately predicted. The analysis of our samples was carried out using the FOSS DS 2500 F from INERA and the ILRI (International Livestock Research Institute) Global Feed Equation was used for the prediction of the various parameters.

The following chemical parameters were sought:

- Total Nitrogenous Matter (TNM);
- Mineral Matter (MM);
- Organic Matter (OM);
- Fibres: Neutral Detergent Fiber (NDF), Acid Detergent Fiber (ADF) and Acid Detergent Lignin (ADL), Crude cellulose (CB);
- dry Matter digestibility (dMS) and organic matter digestibility (dMO).

3.2.3. Data Analysis

Once the data had been collected using the Kobocollect application, it was imported into Microsoft Excel 2013 to create tables and graphs. QGIS software was also used to design the study area map. For statistical analysis, R software version 4.2.2 was used for the Analysis of Variance (ANOVA). The data were also subjected to a Principal Component Analysis (PCA) at the 5% threshold. Finally, a Pearson correlation test was performed between the quantity of pods collected and DHP measured.

4. Results and Discussion

4.1. Variability of Flowering and Fruiting Phases in P. thonningii

Observations of the phenological stages of flowering and fruiting of *P. thonningii* plants at four sites during different months of the year indicate that the flowering phase begins in July and ends in October at the Guena and Tondogosso sites. On the other hand, flowering took place between August and October at the Dafinso and Nasso sites (**Table 3**). The fruiting phase begins in late August and early September and ends in early December at the Guena and Tondogosso sites. Drying of mature pods begins in January at the Guena and Tondogosso sites. For the Dafinso and Nasso sites, the fruiting phase takes place between mid-September and the end of December, and drying of the mature pods begins in mid-January (**Table 3**).

The periodic variability of flowering and fruiting between sites and individuals could be due to the irregularity and poor distribution of rainfall in time and space, as well as soil types. As a result, the duration of flowering and fruiting varies with the abundance and distribution of rainfall, and also varies from one individual to another [22]. In addition, the flowering phases depend on temperature, humidity and hours of sunshine, since an increase in these parameters triggers flowering [23]. Other authors, such as [24], believe that phenology does not depend directly on rainfall and the number of rainy days. They also state that flowering varies from one station to another, from one individual to another, and from one population to another. The influence of the environment is decisive in the behaviour of plants, which tend to shorten their cycle in an environment with an impulsive climate

[25]. In our study, *Piliostigma thonningii* flowered between July and November. Furthermore, the work of [26] has shown that *Piliostigma thonningii* flowers are between December and June in the Sahel, and flowers are from November to March in Ethiopia, while in southern Africa, the flowering period is from November to June. It also emerges that the flowering period of *P. thonningii* is similar to that of other species such as *Acacia senegal* and *Acacia tortilis* var. *raddiana* (reported in the study by [22], which notes that these two species flower between August and December and between June and November respectively. The same applies to *P. reticulatum*, which starts flowering in July in the Sudano-Sahelian zone [27]. However, our results on fruiting are different from those obtained by [22] for species such as *Acacia senegal*, whose fruiting phase varies between October and May, and Boscia senegalensis, which maintains its fruiting phase throughout the year, with the exception of October. Generally speaking, there is asynchronism at the start of flowering and fruiting.

Table 3. Evolution of flowering and fruiting of *P. thonningii* over time (n = 10 individuals per site).

Sites	Characteristics	Phenological stagess	Jul.	Aug	Sept.	Oct.	Nov.	Déc.	Jan.	Feb.	Mar	April	May	Jun
Dafinso (site 1)	Flowering	f1												
		f2												
		f3												
	Fructification	F1												
		F2												
		F3												
Guena (site 2)	Flowering	f1												
		f2												
		f3												
	Fructification	F1												
		F2												
		F3												
Nasso (site 3)	Flowering	f1												
		f2												
		f3												
	Fructification	F1												
		F2												
		F3												
Tondogosso (site 4)	Flowering	f1												
		f2												
		f3												
	Fructification	F1												
		F2												
		F3												

The colours indicate the characteristics of the phases: yellow for flowering and green for fruiting.

The overlap between flowering and fruiting, depending on the site and the individual trees, could be explained by the fact that the trees come from trees of different ages, crown circumferences and even individual sizes. According to [28], the size and age of individuals influence the different phenological stages within the same species. For example, the work of [29] has shown that *Commiphora africana* only begins to bear flowers when the trunk circumference reaches 28 to 30 cm.

The static analysis shows that there are no significant differences between fruiting durations at the different study sites. (See Table 4)

Table 4. Static analysis of fruiting durations between sites.

Df	Sum Sq	Mean Sq	F value	Pr (>F)
3	134.54	44.85	0.33	0.80
18	2.41	134.00		

4.2. Assessment of Production and Correlation between DHP and the Quantity of *P. thonningii* Pods

The correlation circle for the variables quantity of pods produced and diameter at breast height (DHP) shows a strong positive correlation between the parameters (Figure 2). All dimensions represent 100% of the initial information.

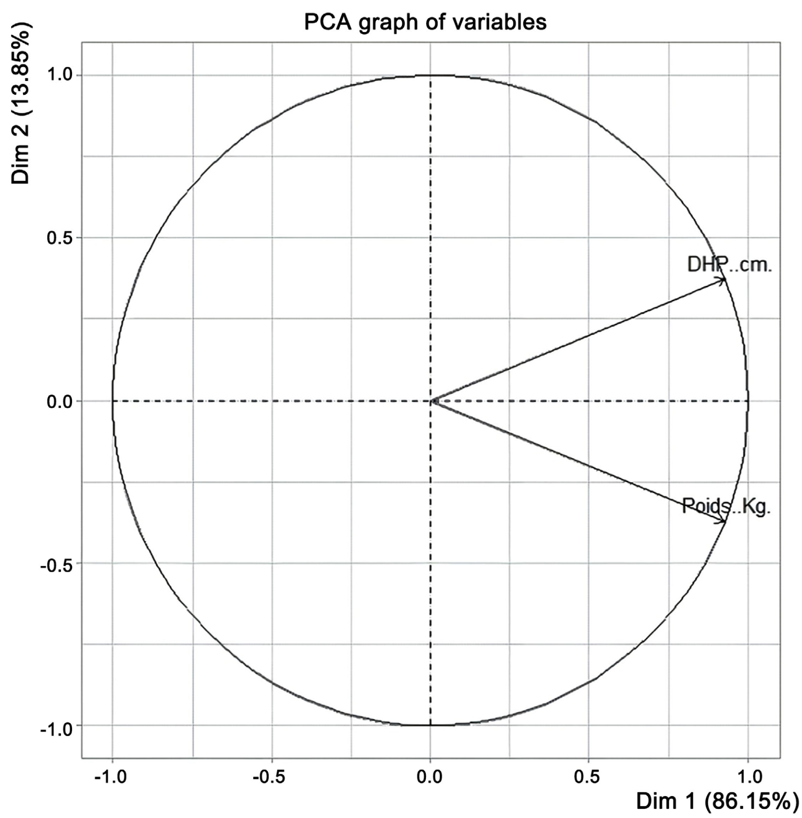

Figure 2. Correlation circle for the variables.

The correlation observed in this series between the fruit production data and the DHP was 0.72. This corresponds to a t-value of 3.626. This corresponds to a t-value of 3.626. With a p-value of 0.003, which is below the significance threshold = 0.05. We can therefore reject Ho and conclude that the correlation between the two variables is significantly positive. The confidence interval was 0.31 to 0.90. The model established between these two variables indicates that the slope was 0.30 with an intercept of −0.90. These results were significant at the 5% level (Table 5).

The average production of *P. thonningii* was estimated at 6.62 ± 3 kg of dry pods per tree, with a total number of 40 flowering plants, 62.5% of which fruited (Table 5).

Table 5. Productivity of *Piliostigma thonningii*.

Number of individuals	Individuals fruiting plants (%)		$\mu \pm$ sd (kg/ft)
Flowering	Male	Female	6.62 ± 3.0
40	37.50	62.50	

4.3. Pod Production Potential of *P. thonningii*

The significant and positive correlation between diameter at breast height and the quantity of fruit produced per tree of *P. thonningii* corroborates the work carried out by [30] and [31] on fruit species. According to these authors, dendrometric parameters and fruit production are strongly positively correlated. Similarly, [32] also obtained a positive correlation between the fruit production of *P. reticulatum* and its various physical parameters such as diameter, height, basal area and crown area. These correlations indicate that in *P. thonningii* stands, the larger the diameter of the trees, the greater the pod yield [33]. On the other hand, a negative correlation between diameter and Vitellaria paradoxa production was obtained by [34], who asserted that good-producing trees are small; the larger the trees, the less they produce.

With regard to the productivity of *P. thonningii*, our results corroborate the production of *P. reticulatum* estimated at an average of 6 kg of dry pods per tree obtained by [35] at Budtenga. On the other hand, our results are higher than those of [32] at Budtenga in two different environments, who obtained an average production per tree of 4.27 and 4.52 kg of dry pods per tree respectively for the plateau and lowland sites of *P. reticulatum* [32]. Previous work carried out by [36] in the northern Sudanian zone noted that 30% to 40% of *P. reticulatum* trees do not produce pods. The low fruiting rate, or even the absence of fruiting, could be explained by the dioecious nature of the species (non-fruiting male plants and fruiting female plants [10]. In addition, mature pods are often attacked by parasites, which could explain the poor quality of the dry pods produced [11]. The intensity and frequency of rainfall, the grazing regime, bush fires [37] and the nature of the soil all affect production [38].

4.4. Variation in the Chemical Composition and Physical Parameters of *P. thonningii* Pods

Analyses of the bromatological composition of the pods show that the Dry Matter (DM) content varies from 91.61% to 93.20%, while the Mineral Matter (MM) content varies from 4.04% to 7.83% MS, and the Total Nitrogen Matter (TNM) content varies from 5.95% to 12.88% MS. With regard to the total walls, the crude cellulose (CB) content ranged from 8.96% to 34.39% MS, while the fibre content varied between 48.06% - 64.30% MS for the Neutral Detergent Fibre (NDF) and between 35.94% - 46.61% MS for the Acid Detergent Fibre (ADF), while the lignin (ADL) content varied between 17.06% and 20.15% MS. As for the different digestibilities (dMS and dMO), their contents vary from 24.58% to 45.35% MS for Dry Matter (DM) and from 22.30% to 43.63% MS for Organic Matter (OM) (Table 6).

Table 6. Chemical composition and nutritional value of *P. thonningii* pods according to harvest dates.

Harvest dates	DM (%)	MM (%DM)	MAT (%DM)	CB (%DM)	NDF (%DM)	ADF (%DM)	ADL (%DM)	dMS (%DM)	dMO (%OM)	MAD (%DM)
HD1	91.61	7.83	12.88	10.22	48.06	35.94	19.76	41.16	36.88	84.47
HD2	91.88	6.18	11.83	8.96	54.41	39.44	20.15	33.21	30.71	74.73
HD3	92.78	4.30	8.43	24.39	59.61	41.76	17.73	27.80	25.40	43.15
HD4	92.65	6.00	7.40	20.77	55.93	40.36	17.16	26.53	24.64	33.56
HD5	93.20	4.06	7.16	34.39	64.30	44.77	17.06	24.58	22.76	31.35
HD6	92.67	4.04	6.24	31.72	64.16	46.61	18.07	24.61	22.30	22.73
HD7	92.69	4.36	6.79	29.01	64.26	46.40	18.36	33.96	32.23	27.87
HD8	93.11	4.13	5.95	28.65	61.62	44.72	17.43	37.36	35.57	20.20
HD9	92.62	4.26	6.13	26.24	60.14	43.87	17.77	45.35	43.63	21.71

DM: Dry Matter, MM: Mineral Matter, MAT: Total nitrogenous matter, CB: crude Cellulose, NDF: Neutral Detergent Fibre, ADF: Acid Detergent Fibre, ADL: lignin, dMS: dry Matter digestibility, dMO: digestibility of organic matter.

Changes in Total Nitrogenous Matter (TNM) and Acid Detergent Lignin (ADL) content, as well as plant length and diameter at different harvest dates, show that TNM content falls progressively from the 1st to the 5th pod harvest date, then stabilises with a slight increase around the 9th pod harvest date. On the other hand, the DLA content remained relatively stable throughout the harvest periods, with a slight decrease around the 5th pod harvest date, followed by a tendency to stabilise.

As for the physical parameters, pod length increased steadily from the 1st to the 5th date, reaching a plateau around the 6th date and remaining relatively stable until the 9th date. Similarly, pod diameter increased progressively from the 1st to the 5th date, then stabilised with slight variations until the 9th date (Figure 3).

The contents of the various constituents of *P. thonningii* pods harvested at different stages of development are generally variable. The same phenomenon has been observed in *Piliostigma reticulatum* [32]. In fact, the nitrogen content increases at a certain period. This is thought to be linked to seed formation and development. Furthermore, in legumes, the seeds contained in the pods store more protein and the pods develop in line with the seeds [32]. These results confirm those of [32], who mentions in his study a loss of MAT content during the period between the growth phase and seed formation. In general, however, MAT content decreases with pod age. This decrease in MAT content may be due to the dilution of nitrogen with the growth in plant biomass. The same observation was made by [5], who, in his studies, stipulated that young Balanites aegyptiaca leaves (223 g/kg DM) have higher MAT contents than older ones (94 g/kg DM). The study by [39] on jujube showed a decrease in the content of chemical constituents (MAT) with the season and phenological stage of the species.

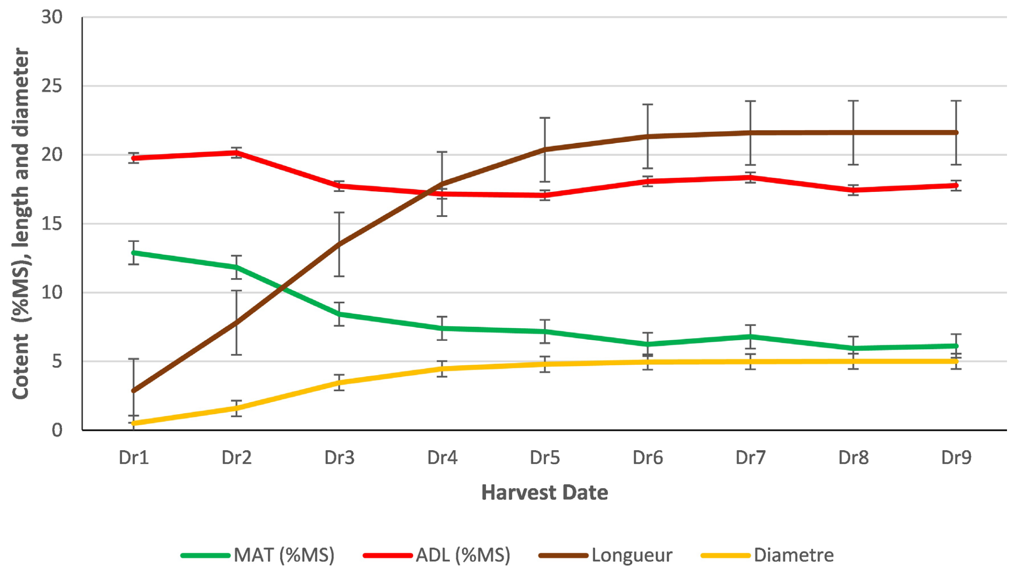

Figure 3. Changes in the content and physical parameters of *Piliostigma thonningii* pods as a function of time.

With regard to parietal fibre content, the relatively stable lignin content indicates that pod ripening does not significantly increase lignification after a certain period. However, the lignin content decreases with the age of the pod, and our results are in line with those obtained by [40], who obtained a lignin content of 15.38% DM with young leaves of *S. setigera*, and [41] with *Leucaena leucocephala*, with a lignin content of 17.54% DM. However, our lignin content is lower than that reported by [5], whose lignin content of Balanites aegyptiaca leaves in a hot dry period is 29.1% DM. This variability in content could be due to age, organ, species and period. [37] state that the season and phenological stage influence lignin content. Similarly, [42] stresses that temperature causes a variation in lignin content in leaves because, with heat, some plants increase their lignin content to reduce water loss.

As for variations in pod physical parameters, the regular increase in pod length up to the 5th date indicates a phase of active growth, followed by stabilisation, which could explain the reaching of maturity. Similarly, the progressive increase in pod diameter up to the 5th date, followed by a stabilisation, suggests a radial development of the pods in parallel with the increase in length. In view of the results of the chemical composition and the development of the physical parameters of the pods, it would be advisable to harvest between Dr6 and Dr7, which would give a good MAT rate and avoid pod attacks, as emphasised by [11] According to [43] Cell wall concentration and digestibility limit the ingestion potential and energy availability of forage crops. He points out that lignin is the key element limiting cell wall digestibility. The high lignin contents (17% - 20% DM) of our pods could be a limiting factor in the digestibility of forages, as they restrict the access of microorganisms to cellulose and hemicellulose, thus reducing the energy available to the animal. [43] notes that voluntary ingestion of forages is a key determinant of animal performance, and the concentration of cell walls is negatively correlated with ruminant ingestion. To overcome this constraint, it is recommended to combine these resources with more digestible supplements such as bran, cakes or low-lignification crop residues, in order to rebalance the energy intake. The addition of bamboo charcoal (1 g/kg PB) according to [15] is also a promising strategy, as it helps to mitigate the effect of antinutritional compounds and improve digestive health, which results in a better use of the ration at breeding.

5. Conclusion

This study has provided information on the phenological cycle, the chemical composition and the physical parameters of the pods and the productivity of the species. Monitoring of changes in the various parameters of *P. thonningii* pods did not reveal any major variations in length, diameter or chemical composition at any stage of their development. There is therefore an advantage in anticipating harvesting, given that dry pods are attacked by insects, and it would be desirable to harvest them when the physical parameters of the pods do not change, at the latest when they begin to dry. *Piliostigma thonningii* is an interesting forage species in terms of its acceptable productivity of pods, their easy accessibility by humans and, above all, their availability during the lean season. In addition to its value as animal fodder, its economic value should not be overlooked, as harvesting all the pods is an income-generating activity. Poor human practices (deforestation, bush fires) should also be taken into consideration, as they could limit the future regeneration of the species.

Conflicts of Interest

The authors declare no conflicts of interest.

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