Chemical composition and Nutritional profile of commercial pelleted feeds and grasses used in rabbit production in southern Benin.

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Summary

This study evaluated the chemical composition and nutritional profile of fifteen tropical grasses and five commercial pelleted feeds used to feed rabbits in southern Benin. Analyses covered dry matter, nitrogenous matter (crude protein), fiber fractions (NDF, ADF, ADL), fat, crude ash, as well as minerals and trace elements. The results show great variability in the nutritional values of the forages studied. Legumes such as *Moringa oleifera* (26.2% DM) and *Leucaena leucocephala* (20.7% DM) stand out for their high protein content, while grasses such as *Elaeis guineensis* have high indigestible fiber content (ADL: 23.3% DM), which limits their digestibility and use in feed. For pelleted feeds, important variations were observed in nitrogen matter (11.2 to 26.9% DM), fiber (ADF: 10.3 to 24.9% DM) and minerals (Ca: <0.1 to 22.4 mg/kg DM). Hence, these variations could affect zootechnical performance, digestive health and farm profitability. This study highlights the importance of characterizing local forage resources and standardizing feed formulations to guarantee a balanced diet that meets standards and recommendations for rabbit needs (growth, reproduction, maintenance), and to support the sustainability of rabbit production in Benin

Keywords: Tropical forage, Pelleted feed, Rabbits, Chemical composition, Animal nutrition, Sustainability.

Résumé

Cette étude a évalué la composition chimique et le profil nutritionnel de quinze fourrages tropicaux et cinq aliments granulés commerciaux utilisés dans l'alimentation des lapins au Sud du Bénin. Les analyses ont porté sur les teneurs en matière sèche, matières azotées (protéines brutes), fractions de fibres (NDF, ADF, ADL), matières grasses, cendres brutes, ainsi que les minéraux et oligo-éléments. Les résultats montrent une grande variabilité des valeurs nutritionnelles des fourrages étudiés. Les légumineuses comme *Moringa oleifera* (26,2 % MS) et *Leucaena leucocephala* (20,7 % MS) se distinguent par leur richesse en protéines, tandis que les fourrages tels que *Elaeis guineensis* présentent des teneurs élevées en fibres indigestibles (ADL : 23,3 % MS), ce qui limite leur digestibilité et leur utilisation dans l'alimentation. En ce qui concerne les aliments granulés, des écarts significatifs ont été observés dans la matière azotée (11,2 à 26,9 % MS), les fibres (ADF : 10,3 à 24,9 % MS) et les minéraux (Ca : <0,1 à 22,4 mg/kg MS). Ces variations pourraient affecter la performance zootechnique, la santé digestive et la rentabilité des élevages. Cette étude met en évidence l'importance de la caractérisation des ressources fourragères locales et de standardiser les formulations alimentaires pour garantir une alimentation équilibrée répondant aux normes et aux recommandations sur les besoins des lapins (croissance, reproduction, maintenance) et, soutenir la durabilité de la production cunicole au Bénin.

Mots-clés : Fourrages tropicaux, Aliments granulés, Lapins, Composition chimique, Nutrition animale, Durabilité.

Introduction

Livestock farming in West Africa is a crucial economic and social pillar, contributing significantly to food security and representing a fundamental source of income for farmers (Molina-Flores et al., 2020). In Benin, rabbit farming is undergoing remarkable development. For almost a decade now, rabbit production has emerged as a promising sector in Benin. It represents an alternative to conventional animal species such as pigs, cattle and sheep. However, rabbit farming remains hampered by major structural challenges, including insufficient supplies of balanced and economically accessible feed, feed quality that sometimes does not meet the recommended nutritional requirements of rabbits, and the absence of standards and quality control for granulated rabbit feed, (Aholou, *et al.*, 2020; FAO, 2018). Commercial feeds, most of whose ingredients are often imported, remain financially inaccessible to most small-scale breeders, justifying the exploitation of undervalued local forage resources (Lukefahr *et al.*, 2022). In recent years, research by Jimoh *et al.* (2024) and Sévérin *et al.* (2022) has encouraged the use of tropical plants with promising nutritional potential in rabbit feed. However, optimal use of forage plants requires more precise characterization of their chemical composition to better define the limits of their consideration as an ingredient (Leone et al., 2015; Saini et al., 2020).

In Benin, recent data on the complete nutritional profiles (macronutrients, minerals, trace elements) of local forages for rabbits are sorely lacking. Indeed, although some recommendations exist on the optimal composition of rabbit feeds (Lebas, 2004), their adaptation to local forage resources remains a major challenge. Unresolved details on the chemical composition of these feed resources hamper their rational integration into rations, as highlighted by the work of Tchetan et al. (2022) and Musco et al. (2016). This study aims to fill this information gap by determining the detailed chemical composition of some tropical forage resources that can be used in rabbit diets and balanced feeds marketed in Benin. The results will make it possible to assess their suitability for the nutritional needs of rabbits, in particular their fiber, protein and fat contents, in order to facilitate the valorization of these forage resources in sustainable and economical feed formulas.

Materials and methods

Study areas

Benin, located in West Africa between 6°30'-12°30' north latitude and 1°-3°40' east longitude, covers an area of 114,763 km². It is bordered by the Atlantic Ocean to the south, Togo to the west, Nigeria to the east, Niger to the northeast and Burkina Faso to the northwest (Adomou, 2005). This study was conducted in southern Benin, in the Departments of Atlantic , Littoral, Ouémé, Plateau, Mono and Couffo (Figure 1) due to the importance of rabbit production (FAO, 2018). The region enjoys a sub-equatorial climate, with annual rainfall between 900 and 1,500 mm and temperatures ranging from 25 to 30°C (Ahossin *et al.,* 2023).

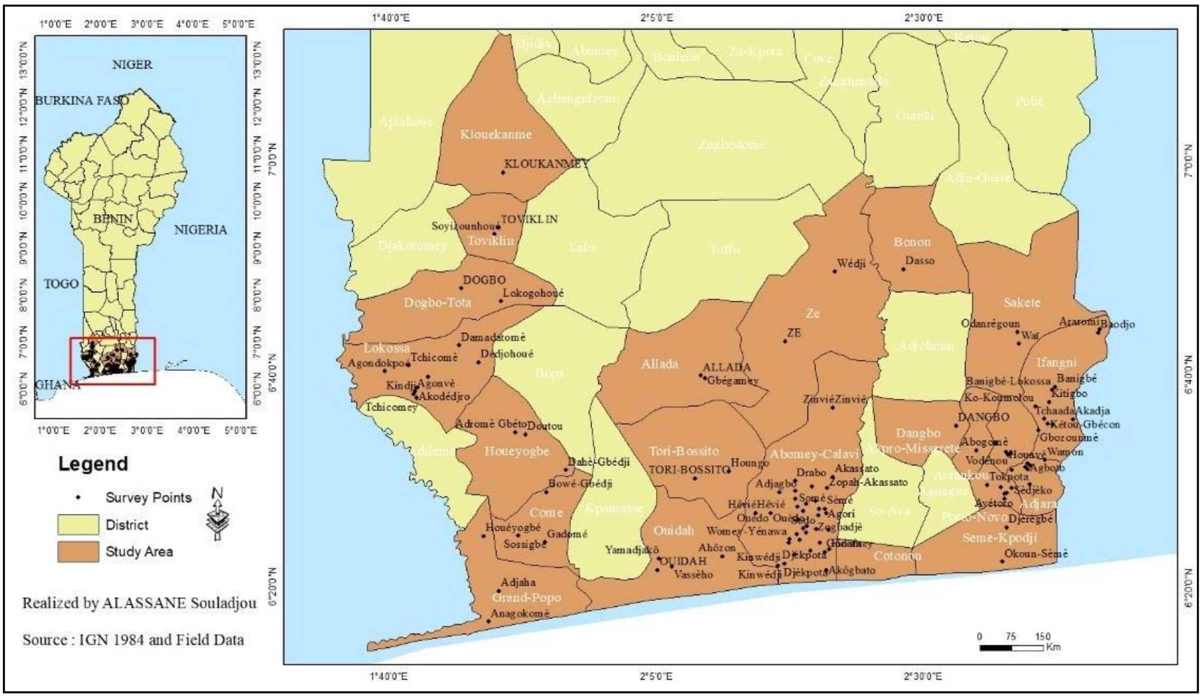

Figure 1: Geographical location of study area

Methodology for collecting and conditioning forage samples

Sample collection

Composite sampling, based on a mixture of samples from several areas, in line with animal nutrition sampling protocols (Van Soest et al., 1991), was adopted. Fodder samples were collected during the wet season (July-August) to ensure that the forage resources available in southern Benin were representative. Fifteen (15) forage species were analyzed. Except for *Panicum maximum* C1, sampled specifically on the agrostology farm of the Faculty of Agronomic Sciences of the University of Abomey-Calavi (UAC), each sample analyzed resulted from a composite mixture representative of the six departments concerned. For each species, three (03) samples were collected in each of the departments studied (Atlantic, Littoral, Ouémé, Mono, Couffo and Zou), i.e. a total of 18 raw samples per species, which were mixed to obtain a homogeneous sample per species to be analyzed.

The open-air, shade-drying method in accordance with FAO (2011) general recommendations for the preservation of forage samples was used. Collected samples were air-dried in the shade to preserve their nutritional quality and avoid degradation of heat-sensitive compounds. The duration of dehydration varied according to the type of forage. Grasses (*Panicum maximum* local and C1, Pennisetum purpureum), rapid drying, between 3 and 5 days. Legumes (*Moringa* *oleifera, Leucaena leucocephala, Cajanus cajan, Gliricidia sepium, Talinum triangulare, Tridax procumbens, Carica papaya, Manihot esculenta, Musa acuminata*), longer drying, between 5 and 8 days, adapted according to their water composition. To prevent mould formation, drying was carried out on laboratory benches at UAC's Faculté des Sciences Agronomiques, ensuring adequate aeration and reducing the risk of contamination.

After drying, the samples were ground using a mill fitted with a 2 mm sieve, in accordance with recommended analytical standards for forage chemical composition analysis (AOAC, 2005). The ground samples were then stored in hermetically sealed, labelled plastic boxes, to ensure traceability and proper preservation prior to chemical analysis.

For the sampling of commercial complete feeds, three types of commercial complete rabbit feeds were targeted: grower feeds, breeder feeds and multi-purpose (or mixed) feeds. For each type, two sampling campaigns were carried out at two distinct periods, six weeks apart, in order to assess the stability of their nutritional composition over time. Samples were taken from randomly selected authorized distributors in three localities representative of the distribution circuit. For each food category and for each period, three bags from three different batches were sampled. A 50 g sub-sample was taken at random from each bag (quartillage method), then homogenized to form a composite sample of 150 kg per type of food and per period. Composite samples were packaged in airtight plastic boxes, labelled and stored in a dark, dry place at room temperature until analysis.

Analysis of the chemical composition of fodder and balanced feed consumed by rabbits in Benin

The balanced feeds were analyzed by the Eurofins Agro laboratory, Wageningen (NL). Eurofins determines the nutritional composition of forages using near infrared spectroscopy on samples dried and ground to 1 mm. (Https://www.eurofins.fr/agroalimentaire/solutions-par-produits/alimentation-animale/)

Forages were analyzed according to conventional methods used in the feed industry or nutrition laboratories. Dry matter (DM) was determined after 24 h oven drying at 103°C, in accordance with the standard established by the European Group on Rabbit Nutrition (EGRAN, 2001). Fiber fractions of forage samples were determined using the Van Soest method (Van Soest *et al.,* 1991), adapted to the FiberBag technic, allowing quantification of both neutral detergent fiber (NDF) and acid detergent fiber (ADF).

For NDF determination, 1 g of ground sample was placed in a polyester filter bag (FiberBag) and subjected to extraction with 100 ml of neutral detergent solution (sodium borate, EDTA, sodium lauryl sulfate, ethylene glycol monoethyl ether and disodium phosphate) to which 0.5 g of sodium sulfite and a few drops of octilic alcohol had been added. Boiling was maintained for 60 minutes under reflux in a continuously stirred digestion system (Mertens, 2002). After automated filtration, FiberBags were rinsed three times with distilled water. Samples were dried at 105°C for 8 hours, cooled in a desiccator and weighed for NDF calculation. Incineration in a muffle furnace at 550°C for 6 hours was used to determine insoluble ash in the NDF.

NDF % = (Crucible weight + Residue weight) - Crucible weight / Sample weight x 100.

The procedure for ADF determination followed a similar protocol. After weighing 1 g of sample into a FiberBag, the fibers were extracted with 100 ml of acid detergent solution (cetyltrimethylammonium bromide and 1 N sulfuric acid), under reflux for 60 minutes (Goering & Van Soest, 1970). Samples were then filtered, rinsed, dried and weighed for ADF quantification. Incineration at 550°C was used to assess insoluble ash in ADF.

ADF % = (Crucible weight + Residue weight) - Crucible weight / Sample weight x 100.

Acid-detersive lignin (ADL) was determined after hydrolysis of ADF residues with 72% sulfuric acid, using the method of Goering and Van Soest (1970). Crude cellulose was quantified using the Weende method, in accordance with AFNOR V18-100 standards (AFNOR, 1997). Ethereal extracts were determined by the Soxhlet method, using petroleum ether as the extraction solvent (AOAC, 2005). For this analysis, 2 g of ground sample was placed in a cellulose cartridge and subjected to continuous extraction for 6 hours in a Soxhlet apparatus, using approximately 150 ml of petroleum ether heated to reflux. After extraction, the solvent was evaporated using a rotary evaporator, and the lipid residue was dried at 105°C for 1 hour, then weighed. The ethereal extract content was calculated according to the formula:

Ethereal extracts (%) = [(Weight of flask after evaporation - Weight of empty flask) / Weight of sample] × 100.

Crude protein was determined using the Kjeldahl method, which measures total nitrogen on dry matter. For this, approximately 1 g of dried sample was weighed and subjected to digestion in a Kjeldahl flask with 10 ml concentrated sodium hydroxide (NaOH) and 10 ml copper sulfate ($CuSO_4$), in the presence of a catalyst. After digestion, the ammonia released was distilled into a receiver containing boric acid solution, then titrated with hydrochloric acid (HCl) solution. The nitrogen content was calculated from the volume of acid used, and the crude protein content was estimated by multiplying the nitrogen content by a conversion factor of 6.25.

Results

Nutritional characteristics of commercial balanced feeds distributed to rabbit in Benin

Rabbit feeds were collected and analyzed to assess their nutritional values, thus providing an overview of the nutritional quality of rabbit feeds marketed in Benin. These analyses considered dry matter (DM), crude ash (CA), total nitrogenous matter (TNM), fat (F), crude cellulose (CC), neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin (ADL). In general, the chemical compositions of commercial feeds were highly variable, with the values analyzed sometimes falling short of or below the recommended nutritional requirements for rabbit production.

For example, the values recorded in the two feeds (C1 and C2) for growing rabbits showed very wide variations (Table 1). The nitrogen content of feed C1 was very high (18.7%), while feed C2 had a low nitrogen content (11.2%). In the case of feeds for breeding females, protein levels also varied significantly between feeds R1 and R2. Nitrogen content was higher in R2 (22.8 g/kg DM) than in R1 (17.6 g/kg DM). The protein value of mixed feed was the highest (25.9 g/kg DM) compared with the Growth and Breeding feeds. In general, fat content was moderate in all feeds, ranging from 2.5% to 4%, except in the C1 Growth feed, which had the highest fat content (7.2%).

Crude Fiber (CF) values were highest in the Mixed feed (18.7%) and lowest in the C1 growth feed (13.9%). However, growth feeds C2 (16.3%), breeding feed R1 (17.6%) and R2 (15.0%) showed intermediate CF levels. NDF values followed the same trends, with higher values for mixed (43.0%) and C1 growth (38.0%) feeds. Growth feed C2 (36.7%), and breeding feed R1 (31.9%) and R2 (30.4%) showed intermediate NDF values. Lignin levels were highest in the mixed feed (7.4%), followed by the C1 (5.0%) and C2 (5.7%) growth feeds, while the R1 (3.4%) and R2 (2.3%) breeding feeds had the lowest lignin levels. ADF values ranged from 20.4% to 24.9%, although a very low value was recorded for the R2 breeder feed (10.3%).

Mineral and trace element content of commercial balanced feeds distributed to rabbit in Benin

Macronutrient and trace element contents of feedstuffs vary considerably (Table 2). Contents of sodium (Na), potassium (K), magnesium (Mg), calcium (Ca), phosphorus (P), sulfur (S) as well as trace elements such as manganese (Mn), zinc (Zn), iron (Fe), copper (Cu), molybdenum (Mo), iodine (I), boron (B), cobalt (Co) and selenium (Se) varied considerably depending on the feed. Na levels in commercial balanced feeds for growing rabbits C2 (0.5 mg) and breeding rabbits R2 (<0.1 mg) are very low, while in other feeds these levels vary between 3 and 3.4 mg. Potassium values ranged from 6.4 mg to 17.4 mg, with a high value recorded in the mixed feed (17.4mg). Magnesium concentrations in the feed ranged from 2.8 to 6.3 mg, with the mixed feed having the highest content (6.3mg). Calcium levels ranged from 0.8 mg to 8.4 mg, while phosphorus levels ranged from 5.4 mg to 11.7 mg. Sulfur values range from 1.3 mg to 4 mg.

Table 1: Variability in the chemical composition of compound feeds distributed on rabbit farms in Benin (g/KgDM).

Feed categories collected	DM	Ash	CP	Fats	CF	NDF	ADF	ADL
Growth feed (C1)	910	110	187	72	139	380	204	50
Growth feed (C2)	903	119	112	40	163	367	198	57
Breeding feed (R1)	887	130	176	25	176	319	223	34
Breeding feed (R2)	958	115	228	38	150	304	103	23
Mixed (M)	940	72	259	36	187	430	249	74

DM: Dry matter; CP: Crude protein; Crude Fiber; NDF: Neutral detergent acid; ADF: Detergent acid fiber; ADL: Detergent acid lignin;

Table 2: Variability in mineral and trace element composition of compound feeds distributed on rabbit farms in Benin. Values are expressed in g/kg$^{-1/}$

Feed categories collected	**Na** (g/kg)	**K** (g/kg)	**Mg** (g/kg)	**C** (g/kg)	**P** (g/kg)	**S** **(g/kg)**	**M** (mg)	**Zn** (mg)	**Fe** (mg)	Cu mg	**Mo** (mg)	**I** (mg)	B (mg)	Co (µg)	**Se** (µg)
Growth (C1)	3.2	9.1	3.	8.4	7.8	1.8	13.9	47	44.6	12.3	1	0.8	6.8	298	376
Growth (C2)	0.5	6.4	2.9	8.1	5.4	1.3	11.6	37	54.6	6.4	0.5	0.4	3	273	116
Breeding feed (R1)	3.4	11.5	5.6	2.24	6.5	3	19.0	16.1	75.4	33.3	0.5	5.8	18.7	820	605
Breeding feed (R2)	<0,1	9.8	2.8	0.8	5.5	2.1	30	58	18.0	29.3	0.4	<0,2	8.3	72	123
Mixed	3	17.4	6.3	2.1	11.7	4	24	67	13.0	14.3	0.9	<0,2	15.8	760	170

Sodium: **Na**; Potassium: **K**; Magnesium: **Mg**; Calcium: **Ca**; Phosphorus: **P**; Sulfur: **S**; Manganese: **Mn**; Zinc: **Zn**; **Iron**: **Fe**; Copper: **Cu**; Molybdenum: **Mo**; Iodine: **I**; Boron: **B**; Cobalt: **Co**; Selenium: **S**

Chemical composition of Benin grasses used in rabbit feed in Benin

Chemical analyses of fodder consumed by rabbits in Benin show considerable variability in content, depending on the botanical characteristics of the plant. These values are essential for assessing nutritional quality and digestibility and enable us to distinguish several groups of forages. For example, taking nitrogen values into account, forages can be classified into three groups: low-protein forages (MAT between 8 and 10%), in this group we find species such as *Panicum maximum* local varieties, *Pennisetum purpureum*, and *Elaeis guineensis* (leaves), forages with average protein contents (MAT between 11 and 15%), this group includes forages such as *Panicum maximum Var C1, Centrosema pubescens, Musa acuminata, Carica papaya,* and *Glircidia sepium, Cajanus cajan, Tridax procumbens, Talinum triangulare.* Forages such as *Sida acuta* (19.9%), *Moringa oleifera* (26.2%), *Leuceana leucocephala* (20.7%) and *Manihot esculenta* (18.2%) are considered protein-rich plants (MAT between 16 and 27%). The lowest Crud Fiber (CF) value is found in *Talinum triangulare,* while *Elaeis guineensis* contains the highest value (33.1%). Other CF values range from 12.5% to 31.5%. NDF levels range from 29.8% (*Glircidia sepium)* to 62.6% (*Elaeis guineensis)*, while ADF levels range from 17.9% (*Glircidia sepium*) to 42.8% (*Elaeis guineensis)*. As for ADL content, the lowest values were recorded with *Glircidia sepium* (5.2%), *Cajanus cajan* (6.1%), *Sida acuta* (7.4%) and *Talinum triangulare* (7.6%), while the other forages contained between 8.9% and 23.3% lignin.

Forages with low nitrogen content are generally characterized by high fiber values. This is the case for forages such as *Elaeis guineensis*, *Panicum maximum* and *Pennisetum purpureum*. Forages rich in nitrogenous matter, such as *Cajanus cajan, Sida acuta, Moringa oleifera, Leuceana leucocephala, Manihot esculenta, Tridax procumbens and Talinum triangulare* have modest fiber contents.

Table 3: Chemical composition of some tropical forages used in rabbit feed in Benin (g/KgDM).

Forage species	DM	Ash	CP	Fats	CF	NDF	ADF	ADL
Elaeis guineensis (leaves)	956	56	82	55	331	626	428	233
Panicum maximum Local Var	954	108	99	18	235	596	367	152
Panicum maximum C1	938	96	119	25	208	538	346	135
Pennisetum purpureum	947	77	88	25	315	523	386	147
*Cajanus cajan (*leaf*)*	946	58	158	39	138	466	206	61
*Sida acuta (*leaf*)*	940	72	199	36	187	430	249	74
Centrosema pubescens	955	77	123	31	132	421	353	126
Moringa oleifera	935	12	262	65	191	386	219	89
Leucaena	958	113	207	61	219	372	232	129
Manihot esculenta	948	98	182	43	125	362	234	94
Musa acuminata	926	39	143	17	198	353	224	127
Tridax procumbens	959	70	158	49	140	331	245	101
*Carica papaya (*leaf*)*	917	22	121	32	188	329	227	112
Talinum triangulare	943	46	156	24	44	303	189	76
Gliciridia sepium	921	94	134	33	134	298	179	52

DM: Dry matter; CP: Crude protein; Crude Fiber; NDF: Neutral detergent acid; ADF: Detergent acid fiber; ADL: Detergent acid lignin

Discussion

Nutritional characteristics of commercial balanced feeds distributed to rabbit in Benin

A diagnostic study of short-cycle farms in Benin carried out by the FAO (2014) and another study on the national strategy for the development of rabbit farming in Benin 2018-2022 carried out also by the FAO (2017) highlighted the main constraints to the development of the sector, identified by the stakeholders themselves. Among these constraints is the lack of quality control of the feed produced and marketed. Our study provided an overview of the quality of commercial feeds and forages used in rabbit production in Benin and thus addressed this major constraint. The results of this study provide an in-depth analysis of the nutritional composition of commercial compound feeds distributed to rabbit in Benin. These data make it possible to assess the suitability of these formulations for the specific needs of growing rabbits and breeding females, while highlighting the discrepancies between the recommended requirements for rabbits and the current compositions of commercial feeds.

Protein content of balanced commercial feeds

In fact, very large discrepancies were observed between the protein contents of growth feeds, breeding feeds and mixed feeds. The protein content of some feeds corresponds to the standards and recommendations for rabbit requirements, while other feeds are below or above rabbit requirements. This wide disparity between feeds for the same physiological stage of the animals indicates a lack of quality control and compliance with commercial feed production standards. Nitrogen is a key component of rabbit feed. It supports protein synthesis for growth, cell repair, milk production and fetal development. In this study, nitrogen levels varied considerably between feed types. For growing rabbits, feed C1 had a crude protein content of 18.7%, values higher than the recommendations of Lukefahr et al., (2022), Lebas et al., (2020) and Moore et al., (2017), which respectively suggest a crude protein intake of 15% for young breeding rabbits, 16% for Angora rabbits and 12 to 16% for young pet rabbits. An excess of protein in the ration could lead to an increase in nitrogen excretion, which can put pressure on elimination organs such as the liver and kidneys and contribute to metabolic imbalances. On the other hand, an excess of protein in the ration could mean an unnecessary extra cost that can reduce production profitability or even the overall digestibility of the ration if the balance between energy and protein is not respected. Furthermore, the crude protein content in our study is in line with that of More et al, (2017) who recommended 17-20% crude protein for larger rabbit breeds. These observations suggest that adapting rations to the specific characteristics of local breed rabbits would be essential to optimize their growth and health. On the other hand, the C2 feed showed a significant deficit (11.2%) compared with the various recommendations for the requirements of growing rabbits. This could compromise metabolism, limit growth and lead to reduced daily weight gain (Lalhriatpuii, et al., 2022; Ismail et al., 2023). In addition, protein deficiency can weaken the immune system, making animals more vulnerable to infections and environmental stresses. In terms of rations distributed to breeding females, R2 feeds (22.8%) slightly exceed crude protein recommendations estimated at between 16.5 and 18.5% by Lukefahr et al., (2022) and 16 to 21% by More et al., (2017). C1 feeds (17.6%) meet recommendations for breeding females. Protein deficiency can disrupt lactation performance, as shown in a study by Nicodemus**,** *et al.* (2007). However, variations in feed composition underline the importance of formulating feeds adapted to specific standards and physiological stages. Protein deficiency can compromise animal health and productivity, while excess can lead to metabolic imbalances. Future research should explore the use of alternative protein sources, to optimize the nutritional quality of rabbit feeds (Pinheiro, *et al.,*2024). The mixed feed had a very high nitrogen content (25.9%), well above the various recommendations. While a high nitrogen content may, on the one hand, contribute to a better supply of the proteins needed for growth and production, on the other, its excess could lead to increased nitrogen excretion. This could place an additional burden on the liver and kidneys, leading to metabolic stress, reduced feed conversion efficiency and, possibly, health problems.

Fiber content of feed and their impact on digestive health

Fiber plays a central role in rabbit digestion, notably by stimulating cecal development and promoting microbial fermentation (Gidenne *et al.,* 2015). The results show notable differences in crude fiber, NDF, ADF and ADL content between feed types. For growing rabbits, feed C2 has a high crude fiber (16.3%), NDF (36.7%), ADF (19.8%) and lignin (ADL: 5.7%) content, slightly exceeding the respective thresholds of (11 to 13%), (27 to 35%), ($16 \leq ADF < 18.5$) and (5 to 5.5%) recommended by Gidenne et al., (2020). These results suggest that excess insoluble fiber in C2 feed may compromise digestibility and absorption of essential nutrients in growing rabbits (Hong *et al.,* 2025; Liu, et al., 2022). Indeed, crude fiber content, particularly of indigestible fractions such as ADL, higher than recommended can lengthen intestinal transit time, reduce feed conversion efficiency and the energy efficiency of rations (Pinheiro, *et al.,* 2024). This could lead to a drop in growth performance, compromising farm profitability. Precise adaptation of formulations to the specific needs of the rabbit breeds raised in Benin would be essential to optimize their health and productivity.

For breeding females, fiber levels are generally better balanced than the values recommended ($ADF > 14\%$; $ADL > 3$) by Pinheiro, et al., (2024), although feed R1 has a slightly higher crude fiber content (17.6%) than the values (14 to 15%) recommended by Lukefahr et al., (2022). Despite a satisfactory overall balance in the fiber content of breeding females, this higher level of crude fiber in feed R1 could reduce the efficiency of digestion. Indeed, less optimal digestion could lead to reduced feed conversion and, consequently, have a negative impact on milk production and fertility. This highlights the need to fine-tune formulations for breeding females to maximize their performance and, by extension, overall rabbit production in Benin. Thus, current formulations could be adjusted to include more digestible alternative fiber sources, to improve digestibility and digestive health.

The mixed feed has a high crude cellulose content (18.7%) and high NDF (43%) and ADF (24.9%) values. Lignin (ADL) reaches 7.4%. Although this feed is rich in protein, its high indigestible fiber content could limit its use in growing or breeding rabbits. Indeed, the excess of insoluble fiber in this mixed feed may reduce digestion efficiency and increase intestinal transit time, which may limit the absorption of essential nutrients in growing or breeding rabbits (Liu, *et al.,* 2022). The use of this category of feed with a higher fiber content could contribute to the health of the digestive system on farms, provided that the ration remains well balanced in energy and protein.

Fats and their energy role

In this study, fat contents ranged from 2.5 to 7.2%. The C1 feed for growing rabbits had a high fat content (7.2%), which may support rapid growth and adipose tissue synthesis. In contrast, feeds for breeding females show lower values (2.5 to 3.8), close to the values (2 to 4% MG) recommended by Lebas *et al.,* (2020). Fat deficiency can limit energy intake during lactation, a period when energy requirements are particularly high (Abdelnour *et al.,* 2022).

Minerals and trace elements

Mineral and trace elements vary considerably between feed types. R1 breeding feeds have high concentrations of calcium (22.4 mg/kg DM) and phosphorus (6.5 mg/kg DM), meeting the ideal Ca/P ratio (1.5:1 to 2:1). On the other hand, R2 shows a marked calcium deficiency (<0.1 mg/kg DM), which could lead to bone disorders and reduced milk production (Gidenne & Fortun-Lamothe, 2002). Zinc, copper and selenium levels were also very high, with insufficient values in some cases. The mixed feed had a selenium content of 170 µg/kg DM, below the values (200 to 300 µg/kg DM) recommended by Gidenne *et al.* (2020). Studies have shown that micronutrient deficiencies can compromise immunity, fertility and general health in rabbits (**Mateos** *et al.,* 2010). Targeted supplementation with minerals and trace elements may be needed to correct these deficiencies and improve zootechnical performance on rabbit farms in Benin.

Bearing in mind that chemical analyses do not always reflect the in vivo bioavailability of nutrients, in vivo studies would be necessary to validate the efficacy of feed formulations for rabbits in Benin. Furthermore, the variability observed between feed types could be due to differences in the raw materials used or in manufacturing processes. Future research should therefore explore the use of alternative raw materials, to improve the nutritional quality of feeds. In addition, longitudinal studies are needed to assess the impact of formulary adjustments on the zootechnical performance and digestive health of rabbits reared in Benin.

Chemical composition of tropical grasses used in rabbit diet in Benin

The results obtained in this study highlighted the nutritional variability of tropical forages commonly used in rabbit feed in Benin. This analysis, based on key parameters such as nitrogenous matter (NM), fiber fractions (crude cellulose, NDF, ADF, ADL), as well as crude fat and ash, makes it possible to assess their nutritional quality and digestible potential. These data are essential for optimizing local resources and feed formulations for rabbits, taking into account their specific needs according to physiological stage (growth, reproduction, and maintenance). The following discussion examines these results from several angles: forage digestibility, protein contribution, energy impact, and practical implications for ration formulation.

Fiber fractions

The fiber content of forages is a critical factor in assessing their nutritional values, as it determines the amount of energy and nutrients available to rabbits. The results showed that forage species such as *Panicum maximum* (wild and C1), *Pennisetum purpureum* , and *Elaeis guineensis* (leaves) had high contents of crude cellulose (up to 33.1%), NDF (52.3-62.6%), ADF (up to 42.8%) and ADL (up to 23.3%). These high values indicate a dense cellulose structure and a high proportion of indigestible fibers, which may limit their digestibility in rabbits (Jones *et al.,* 2025). In view of the recommended limits for lignocellulose 16≤ ADF <18.5% (Gidenne et al., 2020) for growing rabbits, unreasoned daily use of these forages could lead to a drop in reproductive performance in females, or even the growth of fattening young. The value of using this category of high-fiber forages in rabbit nutrition lies in their ability to help maintain optimal intestinal transit and prevent digestive disorders such as gastrointestinal stasis (Gidenne, 2015). Therefore, these forages, although abundant and accessible, appear to be poorly suited to the needs of fattening rabbits or breeding females, but could well be potential fiber sources in compound feeds to support their digestive health in growing rabbits.
In contrast, forages such as *Moringa oleifera, Leucaena leucocephala,* and *Manihot esculenta* display more favorable profiles with moderate fiber contents (18≤ ADF <25%) and high crude protein levels of up to 26%. These characteristics suggest better digestibility and a greater contribution to microbial fermentation in the rabbit cecum (Trocino *et al.,* 2020). These species could therefore be preferred in combination with other forages to cover the nutritional needs of rabbits, particularly in extensive breeding systems.

Protein contribution of forages and implications for rabbit feed

Nitrogenous matter is a key indicator of forage protein quality, essential for muscle synthesis, milk production and fetal development. The results showed great variability in crude protein content, ranging from 8.2% for *Elaeis guineensis* to 26.2% for *Moringa oleifera.* These differences could be justified by the botanical characteristics of the species: grasses are generally low in protein (<10% MS), while legumes stand out with much higher contents (>15% MS). These variations have important implications for rabbit nutrition. Current recommendations made by Lukefahr *et al,* (2022), Lebas *et al,* (2020) and Moore *et al,* (2017)) stipulate that growing rabbits require a crude protein content of 14.2 to 16% of dry matter (DM), while breeding females require 16.5 to 18.5% during gestation and up to 19 to 20% during lactation. In this context, protein-rich legumes such as *Moringa oleifera* (26.2%) and *Leucaena leucocephala* (20.7%) could represent valuable resources for improving the protein content of rabbit feed rations. Grasses such as *Panicum maximum* and *Elaeis guineensis*, on the other hand, did not meet the nutritional requirements of rabbits in terms of nitrogen content, and could be supplemented by more concentrated protein sources in rabbit feed formulations. Recent studies have also highlighted the importance of essential amino acids, notably lysine and methionine, in rabbit diets (Maertens *et al.,* 2022). Although the chemical analyses carried out here do not provide details of amino acid composition, it would be relevant to explore this aspect in future research to better understand protein bioavailability in these forages.

Energy intake

Although less discrimination, fat content and crude ash provide additional information on the energy density and mineral profile of forages. Fat content ranges from 1.7% to 6.5%MS, which is relatively moderate. Fat-rich forages such as *Musa acuminata* (6.5 g/kg DM) could contribute to the energy content of rations, although their impact remains limited compared to concentrated energy sources such as cereal grains or vegetable oils.
Crude ash, indicative of mineral content, varies between 1.2 and 11.3% DM. These values suggest that certain forages, such as *Elaeis guineensis* (11.3% MS), could be interesting sources of minerals, although in vivo bioavailability remains to be assessed. Pérez et al (2021) have shown that mineral deficiencies, particularly in calcium, phosphorus and trace elements, can compromise bone health, fertility and immunity in rabbits. These results underline the importance of incorporating mineral-rich forages into rations to correct nutritional imbalances.

On the basis of the results, the forages analysed can be classified into three distinct groups:
Forages low in nitrogen and high in fiber: *Elaeis guineensis, Panicum maximum* (wild and C1), and *Pennisetum purpureum.* Although widely available, these species have low nutritional value and limited digestibility. They are best suited as ballast supplements for adult rabbits undergoing maintenance but need to be combined with concentrated energy and protein sources for young animals or breeding females. Forages with moderate nutrient content: *Cajanus cajan, Sida acuta*, *Centrosema pubescens*, *Tridax procumbens*, *Carica papaya*, *Talinum triangulare*, and *Gliciridia septum*. These species showed a reasonable balance between nitrogen and fiber content, making them suitable for moderate use in rabbit rations. Forages rich in nitrogenous matter such as *Moringa oleifera, Leucaena leucocephala*, *Manihot esculenta*, and *Musa acuminata*. These species stand out for their high crude protein content and favorable fiber profile, making them ideal candidates for improving the nutritional quality of rations.
This classification provides concrete guidelines for formulating balanced rations, combining forages rich in nitrogenous matter with concentrated sources of energy and minerals.

Although this study provides valuable data on the chemical composition of forages, seasonal variability in the nutritional composition of forages could influence their studied feeding properties. In vivo studies would be required to validate the incorporation of these forages into compound feed formulations, or their use as a supplement or in combination, on digestive and zootechnical performance in rabbit farms in Benin.
Future research should explore the use of pre-treatments (e.g. silage, grinding) to improve the digestibility of high-fiber forages in the context of sustainable rabbit feeding.

Conclusion

This study evaluated the chemical composition of fifteen tropical forages and five pelleted feeds used in rabbit diets in Benin. The results show great nutritional variability, particularly in nitrogenous matter, fiber fractions (NDF, ADF, ADL), fat and minerals. Legumes such as *Moringa oleifera* (26.2% DM) and *Leucaena leucocephala* (20.7% DM) stand out for their high protein and favorable fiber profiles, making them suitable for improving ration quality. On the other hand, grasses such as *Elaeis guineensis* and *Panicum maximum* have high indigestible fiber contents (ADL up to 23.3%), limiting their digestibility and practical use. In the case of pelleted feeds, important deviations from current nutritional recommendations were observed, particularly in terms of nitrogen, fiber and minerals (calcium, phosphorus). These variations underline the need for quality control of commercial feeds to enable standardization and harmonization of feed formulations to meet the specific needs of rabbits, in line with the standards and regulations in force in Benin. This study highlights the importance of characterizing local forage resources and optimizing feed formulations to support the sustainability of rabbit production in Benin. It also encourages the use of pre-treatments to improve the digestibility of fiber-rich forages and better valorization of available resources.

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