Performance of rabbit does and weaned kits fed a granulated diet supplemented with Desmodium or Panicum faddors

Gningnini A. Koné,†,1 Margaret Good,‡ Tagouèlbè Tiho,† Koffi M. Konan, Konan R. Nguessan,† and Maryline Koubा§

†Independent Researcher and Private Consultant, A96DX4C Dun Laoghaire, Ireland
‡Agropastoral Management Institute, Peleforo Gon Coulibaly University, Korhogo, Côte d’Ivoire
§Institut National Polytechnique Felix Houphouët Boigny, BP 1313 Yamoussoukro, Côte d’Ivoire
$Institut Agro, INRAE, PEGASE, 35590, Saint Gilles, France
§Independent Researcher and Private Consultant, A96DX4C Dun Laoghaire, Ireland

ABSTRACT
Rabbit production is increasing in developing countries and can play a crucial role in the fight against poverty. The current work assessed the effect on rabbit does’ reproduction and young kits’ growth when either Panicum maximum, common name Guinea grass, or Desmodium tortuosum, common name Beggarweed is included in their diet. Diets ReC and GrC (standard granulated diets) served as control diets, formulated for doe reproduction and kit growth respectively. The trial diets were diets RePan/GrPan (diet ReC/GrC supplemented with dry P. maximum) and diets ReDes/GrDes (diet ReC/GrC supplemented with dry D. tortuosum). Thirty-six primiparous local breed five-month old rabbit does were randomly allocated to one of the three dietary treatments. After a 15-day dietary adaptation period, does were each bred to one of 12, related, breeding males. Does were then assigned to individual maternity cages maintaining the same dietary treatment for the ensuing 65 days of the trial (30 days of gestation + 35 days of suckling). Thus, there were a total of 12 replicates per treatment: diet ReC, diet RePan or diet ReDes. At weaning, 72 kits, from the three adult feed treatment groups, were, while maintaining the integrity of the feed group of their individual mothers, divided into 12 blocks with 6 weaned kits per block, with each block allocated one of the three diets. Thus, for each of the three diets there were four separate blocks, i.e., four replicates, each with six group-housed weaned kits that received a growth diet which contained the same supplement or not as their mother diet to which they had access prior to weaning; the control diet GrC (Composition slightly different from Diet ReC composition) and trial diets GrPan and GrDes over a 3-day transition phase were adapted to the weaned kits physiological state and fed for a total of 56 days. The results indicated that the use of D. tortuosum significantly improved (P < 0.05) litter size, milk quantity, and kit survival rate from birth to weaning as compared with both control and RePan diets. The study showed that after weaning, compared with control and GrPan diets, the use of D. tortuosum increased (P < 0.05) the growth performance of weaned kits, improved meat nutritional quality by reducing (P < 0.05) cholesterol concentration and increasing (P < 0.05) the n-3 fatty acid proportion, and also reduced the individual kit feed cost to slaughter weight.

Key words: Côte d’Ivoire, Desmodium tortuosum, growth, Oryctolagus cuniculus L., Panicum maximum, reproduction

INTRODUCTION
Developing countries of the world exhibit a protein deficiency gap, especially in the protein of animal origin. Rabbit production offering a high reproductive potential presents an interesting possibility to increase animal protein supply. In sub-Saharan African countries, rabbit breeding is an economic source of animal proteins. However, the high cost of commercial feed in developing countries is one of the major limiting factors in achieving maximum rabbit performance (Kouakou et al., 2016). The diet of these animals is based on a standard diet supplemented or not with local faddors.

The leaves and stem of cultivated Ipomea batatas (sweet potatoes) plants (Kouakou et al., 2015), and other plants regarded as weeds such as Centrosema pubescens (butterfly-pea, a legume) (Kimse et al., 2013), Tridax procumbens (coatbuttons) (Adyembo et al., 2014), Euphorbia heterophylla (wild poinsettia) (Kouakou et al., 2015, 2016) are all possible constituents of the rabbit diet.

Desmodium tortuosum (Sw.), or beggarweed, is a leguminous plant from the family of Fabaceae (Leguminosae). Native to tropical America, this plant, used in the past to feed horses, is now indigenous in Africa. The plant is considered as one of the most troublesome peanut weevils but also as a good forage crop for animals (Webster and Cardina, 2004). Morris et al. (2013) described D. tortuosum as a plant that could provide livestock with flavonoids, lipids, and fatty acids which could improve health and consequently performance. In Côte d’Ivoire, freshly cut D. tortuosum is used as a fodder for rabbits but to our knowledge, there is no study on the use of dry D. tortuosum included with commerce-type feed for rabbits, in the form of pellets. Our working hypothesis for this study was that dry D. tortuosum would act on the reproductive performance of rabbit does (breeding females during gestation and lactation) and on the growth performance of their weaned kits (young rabbits).
The principal local fodder used as a supplement for rabbit feed is the cultivated Panicum maximum, (common name Guinea grass) (Kouakou et al., 2015, 2016). Thus, these two locally available fodder plants dry D. tortuosum and dry cultivated P. maximum, were chosen to study for this trial. Rabbit does will be called only does and young rabbits only kits throughout the manuscript.

**MATERIAL AND METHODS**

**Care of Animals**

The animals used were reared and slaughtered in compliance with regulations for the humane care and use of animals in research, according to EU directive 86/609/EEC. (National Authorization to Experiment on alive animals n°3502 delivered to M. Kouba by the French Minister of Agriculture).

**Feed Formulation**

The study was carried out at the experimental farm of the National Polytechnic Institute Felix Houphouët Boigny (INP-HB), at Yamoussoukro, Côte d’Ivoire, in collaboration with The French National Research Institute for Agriculture, Food and Environment (INRAE). The fodders P. maximum and D. tortuosum were harvested from grounds around the INP-HB and then sun-dried for three entire days.

All diets for the study were formulated and granulated at the Animal Science Laboratory of National Polytechnic Institute Felix Houphouët Boigny at Yamoussoukro, Côte d’Ivoire, for the does and the weaned kits. The control diets (diet ReC and diet GrC) were based on the constituents of a commercial pelleted diet (Ivograin, Côte d’Ivoire). Diet ReC and two further trial diets were all formulated as a granular feed: namely diet RePan (diet ReC supplemented with 22% of dry P. maximum (ORSTOM G23)) and diet ReDes (diet ReC supplemented with 35.25% of dry D. tortuosum). The control diet ReC and the trial diets RePan and ReDes, for the does reproduction phase, were formulated to be isoproteic and isoenergetic and the three trial diets were then further adapted, maintaining the isoproteic and isoenergetic properties, as growth diets, GrC, GrPan (diet GrC supplemented with 28% of dry P. maximum (ORSTOM G23)) and GrDes (diet GrC supplemented with 44% of dry D. tortuosum), to meet the weaned kits physiological requirements. Table 1 presents the ingredients and composition of the finalized diets for does and weaned kits. Table 2 presents the chemical composition of the diets ReC and GrC, of the dried P. maximum and of the dried D. tortuosum. The animals were fed twice per day at 08:00 and at 16:00.

**Animals and Experimental Design**

Thirty-six local primiparous does (Oryctolagus cuniculus), 5-month-old, with an average weight of 2,330 g, were used. Three trial groups of 12 does each were randomly selected. One group of 12 was randomly assigned to receive the control diet.

### Table 1. Ingredients and chemical composition of diets for does and for weaned kit diets.

| Rabbit category | Does | Weaned kits |
|-----------------|------|-------------|
|                 | ReC  | RePan       | ReDes | GrC  | GrPan | GrDes |
| **Ingredients, g/kg** |      |             |       |      |       |       |
| Panicum maximum |     | 220         | 0     | 280  | 0     |
| Desmodium tortuosum | 320  | 352.5       | 0     | 440  |       |
| Wheat bran      | 125  | 150         |       | 200  | 167.5 |
| Corn            | 370  | 365         |       | 197.5| 237.5 |
| Soya bean meal  | 125  | 45          |       | 160  | 32.5  |
| Cotton meal     | 135  | 65          |       | 130  | 90    |
| Sugar cane molasses | 10  | 10          |       | 10   |       |
| Salt (NaCl)     | 5    | 5           |       | 10   |       |
| Oyster shell†   | 5    | 5           |       | 10   |       |
| Vitamin-mineral premix‡ | 2.5  |       | 2.5  |       |
| Cost, Euros/kg  | 0.35 | 0.29         | 0.24  | 0.35 | 0.30  |
| **Analyzed content, % dry matter** |      |             |       |      |       |       |
| Dry matter (DM) | 91.7 | 91.4         | 92.6  | 90.0 | 92.4  | 93.0  |
| Fat             | 6.3  | 6.2          | 6.1   | 3.3  | 4.3   | 4.5   |
| Crude fiber     | 13.2 | 13.3         | 13.3  | 14.6 | 13.4  | 13.3  |
| Ash             | 6.0  | 6.0          | 6.0   | 9.6  | 7.4   | 7.6   |
| Crude protein   | 17.3 | 17.2         | 17.2  | 16.0 | 15.8  | 15.9  |
| Gross energy, kcal/kg DM | 4,671 | 4,610      | 4,586 | 4,430| 4,395 | 4,395 |
| Digestible energy, kcal/kg DM | 2,785 | 2,757      | 2,768 | 2,641| 2,595 | 2,609 |

*Table 1. Ingredients and chemical composition of diets for does and for weaned kit diets.*

†Oyster shell contains 95% calcium carbonate.
‡One kilo of premix of vitamins and mineral premix contains: Vitamin A: 12,000 IU; Vitamin D: 1,000 IU; Vitamin E: 55 mg; Vitamin K: 2 mg; Vitamin B1: 2 mg/kg; Vitamin B2: 6.50 mg/kg; Vitamin B6: 3 mg/kg; Vitamin B12: 0.04 mg/kg; Vitamin PP: 55 mg/kg; vitamin C: 200 mg/kg; Panthothenic acid: 20 mg/kg; Folic acid: 5 mg/kg; Choline: 100 mg/kg; Cobalt: 0.88 mg; Copper: 12.7 mg/kg; Iodine: 0.75 mg; Iron: 72 mg/kg; Manganese: 10 mg/kg; Selenium: 0.45 mg; Zinc: 61 mg/kg.
diet ReC (does control diet based on the constituents of a commercial pelleted diet (Ivograin, Côte d’Ivoire)), one group to receive diet RePan (diet ReC supplemented with 22% of dry *P. maximum* (ORSTOM G23)), and the third group to receive diet ReDes (diet ReC supplemented with 35.25% of dry *D. tortuosum*). Does were group-housed (in three collective cages of 12 does, one cage per diet), for a 15 day period of adaptation to the experimental environment including feed transition. At the end of the adaptation period, the does were bred using 12 related-bucks with the males mating pattern being the same for each group (one sire to one doe in each group). The bucks were 6-months-old. They had the same father and their mothers were related to avoid a male effect. However, the bucks used were not related to the does of the trial to avoid an inbreeding effect. To have grouped farrowings, all the matings were due over 1 week. After mating, the does were distributed to individual maternity cages. The cage size was (90 cm × 50 cm × 40 cm) (respectively for length, width, and height) in a covered well-ventilated building. Water and feed were provided ad libitum. Health and mortality of does were monitored daily. The total duration of the experiment was 80 days (15 days of adaptation to the experimental environment including feed transition + 30 days of gestation + 35 days of suckling until weaning).

At weaning, 72 kits with the same average weight, from the three groups of does, were assigned, based on the diets their mothers had received, to 12 groups of 6 kits each (four replicates per diet). Thus, the kits were each maintained on the same diet their mother received but reformulated for growth (as per Table 1) to meet the physiological requirements of the kits. Each group of six kits was allocated to a collective cage of (126 cm in length, 50 cm in width, and 40 cm in height), in a covered well-ventilated building. The available surface per kit was 1,050 cm², and consequently the stocking density was about 9 kits/m². The duration of this study period was 56-days. The transition from does reproduction (Re) diet to the kits reformulated growth (Gr) diet occurred over a 3-day-period for each replicate. To clarify, the kits whose dams had received diet ReC continued to receive a control diet GrC; the kits whose mothers had received diet ReDes were fed reformulated GrDes diet (diet GrC supplemented with 44% of dry *D. tortuosum*). Both reformulated growth diets were isoproteic and isoenergetic. The kits received their respective diets and water ad libitum throughout the study. At the end of the experiment, the rabbits of 13-weeks of age were, after a 12-h-fasting period, electrically stunned and exsanguinated in an experimental slaughterhouse.

Since growing rabbits are highly sensitive to disease, the mortality and health status of the animals were monitored twice daily throughout the study period of 91-days ((35-days, birth to weaning) + (56-days, weaning to slaughter)). An external examination of the rabbits was undertaken to detect: 1) prostrate animals; 2) light, acute or terminal diarrhea; 3) mucus in feces, and 4) animals not included in the previous categories, but with an abnormally low growth rate during a period of one week, according to Fernandez-Carmona et al. (2005). The does weight was recorded at the start, at mating, at farrowing, and at weaning. At farrowing, the kits were weighed and then weighed weekly until slaughtered at 13-weeks of age. Feed intake was measured daily throughout the study. The daily weight gain and feed to weight-gain ratio were calculated for does at the end of gestation and for postweaned kits. The variables measured also included the size (number born) and the weight of the litter, the survival rate of kits and the number and the body weight of weaned kits. Milk production was estimated daily during the entire suckling period. Each doe was separated from her kits for 1 h daily (8:00 a.m. to 9:00 a.m.). The doe was weighed before the kits were returned and allowed to suckle for 15-minutes, and then, each doe was again weighed. Therefore, the change in doe’s weight before and after suckling corresponds to the daily milk production weight. This method was described in the review of Maertens et al. (2006) as the optimal estimation of milk production (Tables 3 and 4). Samples of milk were first collected one day before the lactation peak (MB+16), at the lactation peak (MB+17), and one day after the lactation peak (MB+18). Then, the three samples were pooled for each doe and one sample was collected from the pooled samples. Samples of muscles (*Semimembranosus* and *Longissimus dorsi*) were collected from 13-weeks-old rabbits for analyses (Table 6).

**Table 2.** Chemical composition of control diets (ReC for lactation period) and GrC (for growth period), *Desmodium tortuosum* and *Panicum maximum* used in rabbit diets

| Item                | ReC   | GrC   | *Panicum maximum* | *Desmodium tortuosum* |
|---------------------|-------|-------|-------------------|-----------------------|
| Dry matter          | 91.7  | 90    | 25.8              | 22.9                  |
| Ashes               | 6     | 9.6   | 9.3               | 10.7                  |
| Crude fiber         | 13.2  | 14.6  | 17.4              | 24.9                  |
| Crude protein       | 17.3  | 16.0  | 10.2              | 19.5                  |
| Lipids              | 6.3   | 3.3   | 2.0               | 2.4                   |
| Fatty acids composition, % |       |       |                   |                       |
| ∑SFA                | 39.1  | 39.3  | 33.9              | 37.8                  |
| ∑MUFA               | 22.0  | 23.0  | 15.7              | 6.5                   |
| ∑PUFA               | 38.9  | 37.7  | 50.4              | 55.7                  |
| ∑n-6 PUFA           | 36.5  | 35.4  | 34.0              | 19.2                  |
| ∑n-3 PUFA           | 2.4   | 2.3   | 16.4              | 36.5                  |
| ∑n-6 PUFA ∑n-3 PUFA | 15.2  | 15.1  | 2.1               | 0.5                   |
Chemical Analyses

Total fiber contents were determined for the control diets ReC and GrC, for the two fodders, and for the four trial diets (two reproduction, two growth) using Fibretec System 1021 Cold extractor (Saint Andrè de Cubzac, France) (Tables 1 and 2). Samples of the control diets ReC and GrC, the four trial diets, the two fodders, milk and muscle were analyzed for dry matter, ash and crude protein (N × 6.25) content, according to AOAC (2004). Milk mineral macro-elements were analyzed by Atomic Absorption Spectrometer (Varian Spectraa 20, IET, Mundelein, USA). Lipids were extracted from the same samples (control diets ReC and GrC, fodders, the four trial diets, milk and muscles) by the chloroform/methanol procedure of Folch et al. (1957). Fatty acid composition was measured after methylation of the samples (only ReC, GrC, fodders, milk, and muscles). Fatty acid methyl esters were prepared with brome trifluoride methanol according to Morrison and Smith (1964) and analyzed on an Agilent
Effect of fodders on does and kits nutrition

Table 6. Effect of the diets and for weaned kit diets on the chemical composition of meat (muscle) of 13-week-old kits

| Carcass variables | GrC          | GrPan       | GrDes       | SEM  | P-value |
|-------------------|--------------|-------------|-------------|------|---------|
| Final body weight, g | 1,360<sup>b</sup> | 1,352<sup>b</sup> | 1,679<sup>a</sup> | 47.5 | <0.001  |
| Carcass weight, g  | 721<sup>b</sup>  | 720<sup>b</sup>  | 848<sup>a</sup>  | 26.7 | <0.001  |
| Carcass yield, %   | 53           | 53.2         | 50.5         | 3.10 | 0.65    |

Composition, % of FM†

| Composition       | S† | Ld | S | Ld | S | Ld |
|-------------------|----|----|---|----|---|----|
| Dry matter        | 24.1 | 25.7 | 24.1 | 24.9 | 25.0 | 25.5 | 1.57 | 0.13 |
| Lipids            | 1.7<sup>c</sup> | 2.3<sup>b</sup> | 1.7<sup>c</sup> | 2.1<sup>d</sup> | 1.8<sup>b</sup> | 2.6<sup>d</sup> | 0.10 | <0.001 |
| Proteins          | 21.3 | 21.4 | 20.4 | 21.3 | 21.2 | 21.3 | 1.56 | 0.68 |
| Total cholesterol, mg/100 g | 73.2<sup>b</sup> | 77.4<sup>c</sup> | 72.8<sup>b</sup> | 78.4<sup>d</sup> | 50.1<sup>d</sup> | 55.2<sup>c</sup> | 0.70 | <0.001 |

Fatty acid composition, %

| Fatty acid | ∑ SFA | ∑ MUFA | ∑ PUF A | ∑ n-6 PUF A | ∑ n-3 PUF A | ∑ n-6 PUF A: ∑ n-3 PUF A |
|------------|-------|--------|---------|-------------|-------------|--------------------------|
|            |       |        |         |             |             |                          |
| Dry matter | 42.8  | 41.8   | 42.0    | 40.8        | 43.1        | 41.2                     | 4.50 | 0.24 |
| Lipids     | 33    | 29.7   | 33.8    | 29.2        | 33.5        | 29.1                     | 5.15 | 0.57 |
| Proteins   | 24.2  | 28.5   | 24.2    | 30.0        | 23.4        | 29.7                     | 7.11 | 0.43 |
| Total      | 22<sup>b</sup> | 26.3<sup>a</sup> | 21.8<sup>b</sup> | 27.5<sup>d</sup> | 19.6<sup>b</sup> | 25.5<sup>d</sup> | 3.2  | 0.04 |
| n-6 PUF A  | 2.3<sup>c</sup> | 2.2<sup>c</sup> | 2.4<sup>c</sup> | 2.5<sup>c</sup> | 3.8<sup>b</sup> | 4.2<sup>c</sup> | 0.31 | <0.001 |
| n-3 PUF A  | 9.6<sup>b</sup> | 11.9<sup>a</sup> | 9.1<sup>b</sup> | 11.0<sup>d</sup> | 5.2<sup>c</sup> | 6.1<sup>c</sup> | 1.15 | 0.01 |

†FM = fresh muscle.

<sup>1</sup>Diets: Control diet GrC, experimental diet GrPan (diet GrC supplemented with Panicum maximum); experimental diet Grdes (diet GrC supplemented with Desmodium tortuosum).

<sup>2</sup>Diets* Variable means within rows with no common superscript differ.

<sup>3</sup>FM = fresh muscle.

<sup>4</sup>Ld: Longissimus dorsi muscle.

<sup>5</sup>S: Semimembranosus muscle.

<sup>a–e</sup> SEM = standard error of the mean.

Statistical Analyses

Data were analyzed by the one-way analysis of variance ANOVA option of the generalized linear model (GLM) of R 3.4.2 software (Copyright 2016, R Foundation for Statistical Computing Platform) with diet as the main effect. The statistical model used was $Y_{ijk} = \mu + Di + R_{ij} + \gamma_{ijk}$ where $Y_{ijk}$ = response variables from each individual replication; $\mu$ = the overall mean; $Di$ = the effect of diet; $R_{ij}$ = the inter-experimental unit (replications) error term and $\gamma_{ijk}$ = the intra-experimental unit error term. Least significant difference comparisons were made between treatment means per diet for main effects where there was a significant $F$ value. Significance implies $P < 0.05$. Otherwise ($P > 0.05$), there is no significant difference.

RESULTS

Diets

Diet composition is presented in Tables 1 and 2 shows the chemical composition of control diets and fodders. The Panicum maximum dry matter (DM) percentage was 12.7% greater than the DM percentage of D. tortuosum; however, Panicum maximum fiber and protein percentages were reduced respectively by 43.1% and 91.2% compared with D. tortuosum, the protein content of the control diets ReC and GrC being intermediate and their fiber content less (Table 2). Compared with the control diets ReC and GrC and Panicum maximum, D. tortuosum was very rich in polyunsaturated fatty acids (PUFA) and more especially in n-3 PUFA. Control diets ReC and GrC exhibited more saturated fatty acids (SFA) and monounsaturated fatty acids (MUFA) and less PUFA than the fodders, especially a low content of n-3 PUFA and a high content of n-6 PUFA. Panicum maximum was rich in n-6 PUFA compared with D. tortuosum.

Performance of Does During Gestation and Suckling

Table 3 presents the doe performance variables during gestation and from parturition to weaning. The inclusion of D. tortuosum in the diet resulted in a significant increase ($P < 0.05$) in the average litter size relative to does fed diets ReC, RePan. The weight of the kits at birth was not significantly ($P > 0.05$) affected by the diet (41, 40, and 35.5 g respectively with ReC, RePan, and ReDes), after 30 days of gestation. The other reproduction variables were similar whatever the diet and there was no diet effect ($P > 0.05$) on the feed intake and the feed-to-gain ratio of does.

During suckling, the doe body weight decreased consistently regardless of diet (body weight losses of 5.2%, 4.4%, and 6.1%, respectively with diets ReC, RePan and ReDes). Feeding does with the ReDes diet led to a 2.12% increase ($P < 0.05$) of the total dry matter intake by doe during lactation, compared with the control group ReC, an increase of 580.1 g of weaned rabbits due to increased lactation ($P < 0.05$) compared with the control group ReC. Feeding does with the ReDes diet led also to an increase, by 36.9% and 46.5% ($P < 0.05$), of the number of weaned kits compared...
respectively with the control group ReC or the group RePan, and an increase (P < 0.05) of the survival rate of the kits, by 8.5% (from birth-to-weaning), compared with the does fed diet ReC or RePan. However, there was no (P > 0.05) diet effect on the weight of individual weaned rabbits and on the daily weight gain of young rabbits during suckling (Table 3).

**Performance of Post-weaned Rabbits**

Table 4 presents the performance of post-weaned kits fed diets GrC, GrPan, or GrDes. Feeding kits with the diet GrDes led to an increase (P < 0.05) by 23.8% in final weight and by 33.5% in daily weight gain, an increase (P < 0.05) by 1.2% in total dry matter intake and an improvement (P < 0.05) by 24.2% in the feed to gain ratio (from weaning to the end of the experiment), compared with the kits fed diet GrC or GrPan. Survival rate of kits fed diet GrDes (100%) was greater (P < 0.05) than the survival of kits on diet GrPan (62.5%), the survival rate of kits fed diet GrC being intermediate (87.5%). The feed cost to produce a 13-week-old kit was reduced by 41.1% for kits fed GrDes compared with kits fed GrPan and by 50.4% compared with kits fed diet GrC.

**Milk Composition**

Table 5 presents the effect of the diet on milk composition. The dry matter proportion of the milk was respectively 9.5% and 8.3% greater (P < 0.05) with diet ReDes than with diets ReC and RePan. The fatty acid composition of milk is shown in Table 5. The table presents the effect of the diet on milk composition.
Platycodon grandiflorus. The lipid proportion of the milk was respectively 72.7% and 58.3% greater ($P < 0.05$) with diet ReDes than with diets ReC or RePan. The lowest lipid percentage was found in milk of does fed diet ReC (7.7%). There was no dietary effect ($P > 0.05$) on the protein and the mineral proportions (Ca, K, Mg, and P). The proportion of saturated fatty acids in milk was very high (>60%), for each diet and there was no dietary effect ($P > 0.05$) on this percentage. Among SFA, the percentage of short chain fatty acids (8:0 and 10:0) was also high whatever the diet. Monounsaturated and total polyunsaturated fatty acid proportions were not ($P > 0.05$) affected by the diet. However, feeding the ReDes diet led to a respectively 41.2% and 25.5% greater ($P < 0.05$) n-3 fatty acid proportion, compared with the milk of does fed diet ReC or diet RePan. The n-3:n-6 ratio was respectively 69.5% and 61.4% less ($P < 0.05$) in milk from does fed ReDes than in milk of does fed diet ReC or RePan.

**Carcass Characteristics and Meat Composition**

Table 6 presents the results of carcass weight and yield and the results of muscle composition. Feeding diet GrDes (post-weaning) led to respectively 23.4% and 24.2% heavier ($P < 0.05$) rabbits compared with rabbits fed diet GrC or diet GrPan. Consequently, the carcass weight was greater ($P < 0.05$) in rabbits fed GrDes relative to carcass of rabbits fed diet GrC or diet GrPan but the carcass yield was not ($P > 0.05$) affected by the diet. There was no effect ($P > 0.05$) of the dietary treatment on the dry matter and protein proportions, in both muscles. Lipid proportion was greater ($P < 0.05$) in Longissimus dorsi muscle than in Semimembranosus, whatever the diet. The lipid percentage in Longissimus dorsi was the highest with diet GrDes (2.6%) and the lowest with diet GrPan (2.1%), the lipid percentage with diet GrC being intermediate (2.3%). However, there was no diet effect ($P > 0.05$) on Semimembranosus lipid content. Feeding diet GrDes led to less ($P < 0.05$) cholesterol content in both muscles; this content was decreased by 31.2% and 29.6%, respectively in Semimembranosus muscle and Longissimus dorsi muscle of rabbits fed GrDes diet, compared with rabbits fed GrPan, and decreased by 31.6% and 28.7% compared with rabbits fed diet GrC. There was no ($P > 0.05$) diet effect on proportions of total SFA, MUFA, and PUFA in both muscles. The n-6 fatty acids proportion was greater ($P < 0.05$) in Longissimus dorsi muscle than in Semimembranosus muscle, whatever the diet and there was no dietary effect on the n-6 fatty acid proportion for each muscle. However, feeding GrDes led to an increase ($P < 0.05$) of n-3 fatty acid proportion and a decrease ($P < 0.05$) of n-6:n-3 ratio in both muscles compared with diet GrC or diet GrPan.

**DISCUSSION**

During gestation, does fed diet RePan or ReDes exhibited an increased body weight with on average a total body weight gain of 667 g with an average intake of dry matter of 5.653 g. This is due to the physiological change of the doe. According to Henaff and Jouve (1988), the fetus weight depends on the number of embryos in the uterus and on the nutritional status of the doe. Moreover, this weight gain may also be highly influenced by the feed intake of the doe. The feed to gain ratio was on average 8.4 during gestation, which is similar to the results of Mel and Soro (2015) who found 8.5–9 for gestating does in Côte d’Ivoire.

The litter size observed with diet ReDes was the highest (7.7 kits) relative to diets ReC and RePan. The litter size obtained with the diets ReC and RePan was similar to the results of Toleba et al. (2017), who used a diet supplemented with Azadirachta indica in Benin for local does. However, the litter size obtained with diet ReDes was greater than the results obtained in Benin by Toleba et al. (2017). Indeed the litter size observed with does fed ReDes was similar to the size obtained by Hue-Beauvais et al. (2015) in France with New Zealand does fed a control diet. However, in Poland, Ludwiczak et al. (2021) described a greater litter size of Hycole does. The weight of newborn rabbits (41, 40, and 35.5 g, respectively with diets ReC, ReDes, and RePan) was less than the weight observed in Benin by Toleba et al. (2017), and in Poland by Ludwiczak et al. (2021).

During the suckling period, there is some weight loss for the does whatever the diet. These weight losses were respectively 144, 117, and 155 g with diet ReC, diet RePan, and diet ReDes but they are not significantly different. According to Michel and Bonnet (2012), during the suckling period, does use a lot of energy for milk production to ensure proper development of young rabbits. Consequently, lactation induces a weight-loss for the does to feed their litter. That was also demonstrated in rabbit does in the Netherlands by Rommers et al. (2002) and in Egypt by Salama and Abo El-Azayem (2018). Kits receiving the diet ReC, ReDes, and RePan as well as their maternal milk exhibited an average weight gain of 338 g. This was due to milk and feed. According to Maertens et al. (2006), there is an increase in the daily feed intake of young rabbits starting between 18 and 19 days during the suckling period. The weight gain in the present study during suckling was similar to the results of Kouakou et al. (2016) in Côte d’Ivoire.

The number of weaned rabbits from does receiving diet ReDes was greater than the number of weaned rabbits of the groups of does receiving diet ReC or diet RePan. According to Lebas and Sardi (1968), the capacity of the doe to suckle her litter and consequently to produce milk is the first condition for the survival of newborns from birth to weaning. Indeed, the young rabbit receives exclusively milk during the three first weeks of life. In the present study, D. tortuosum increased the does milk production by 15.6% (diet ReDes) in comparison to diet ReC and 47% in comparison to RePan. This increase in milk production may be due to properties in Desmodium but also may be due to the greater litter size. However, Maertens et al. (2006) reported that the number of suckling kits is the main factor affecting milk yield but if the litter weight is less than 450 g, as is the case in the present study, there is no increase in milk yield when the number of kits increases.

In the present study, the dry matter content of the milk was in accordance with the results of Lebas (2002) and Ludwiczak et al. (2021) in Hycole does. However, except for the milk of does fed ReDes, which was in the same range, the fat proportion of milk from does fed diet ReC or RePan was less than the results obtained by Lebas in 2002, whatever the diet. The protein and ash proportions were also less than the results of Lebas (2002), but were in the range of results of Ludwiczak et al. (2021) for primiparous Hycole does. The fatty acid profile of doe milk was characterized by a high content of short-chain fatty acids, mainly caprylic acid (8:0) and capric acid (10:0), by an average of 61.2% of saturated fatty acids, 15.7% of monounsaturated fatty acids and 22.9% of...
polyunsaturated fatty acids. These were slightly different from results presented by Maertens et al. (2006) (70% saturated fatty acids, 13% monounsaturated fatty acids, and 16% polyunsaturated fatty acids). Comparing the diets, milk from does fed ReDes presented the highest proportion of n-3 fatty acids, with a ratio n-6:n-3 of 5.73. This ratio was less than ratio obtained with diet ReC (8.24) or diet RePan (9.33). Kouba and Mourot (2011) showed that in monogastric animals, the fatty acid composition of their products strictly reflects the fatty acid composition of the diet. The high amount of n-3 fatty acids in the milk of does fed ReDes was linked to the high amount of n-3 fatty acids in D. tortuosum. According to Delgado et al. (2018), the inclusion of n-3 fatty acids might enhance animal health and productivity. In the present study, the use of D. tortuosum led to a greater litter size, greater survival rate, greater milk production, and better growth performance of post-weaned rabbits.

The feed cost of an individual 13-week-old kit from does fed GrDes was very significantly less than the cost of a weaned kit from does fed diet GrC or diet GrPan. This result confirmed the observations of Kouakou et al. (2016) who showed that the use of Euphorbia heterophylla (fodder that can also be used for rabbits in Côte d’Ivoire), decreased the feed cost for rabbit production.

Post weaning, the introduction of D. tortuosum in the feed (diet GrDes) led to a better growth (live and carcass weights) of the animals compared with rabbits fed diet GrC or diet GrPan. Whatever the diet, the weight of the 13-week-old rabbits was greater than the results obtained by Kouakou et al. (2015) (770 and 934 g) for rabbits respectively fed a diet of (P. maximum) supplemented with (Ipomoea batatas) or with (Euphorbia heterophylla). The daily weight gain of 13-week-old rabbits fed GrDes was better than the daily weight gain of rabbits fed diet GrC or diet GrPan. The daily weight gain obtained with diet GrDes was similar to the gain of Californian rabbits (24 g.j⁻¹) with a commercial diet supplemented with green tropical fodder (Centrosera pubescens) (Kimse et al., 2013). It was also similar to the daily weight gain of the local breed (24 g.j⁻¹) with commercial feed for growing rabbits over a period of 8-weeks (Kpodékon et al., 2009). The daily weight gains in the present study were greater than the results of Kouakou et al. (2015) (daily weight gain of 7.9 and 10.5 g.j⁻¹) for rabbits respectively fed a diet of (P. maximum) supplemented with (Ipomoea batatas) or with (Euphorbia heterophylla).

The feed to gain ratio (4.7) for rabbits fed the diet GrDes was less than that observed by Kouakou et al. (2015) (5.7) in post-weaned rabbits fed ad libitum P. maximum supplemented by commercial feed. However, the feed to gain ratio of the present study for rabbits fed GrDes was similar to the results of Adeyemo et al. (2014) with diets constituted of 50 g of concentrate per rabbit per day + 50 g of Tridax procumbens in post-weaned rabbits. This ratio of 4.7 was also in accordance with results of Abu Hasfa and Hassan (2021) in Egypt for New Zealand rabbits fed a diet supplemented with P. maximum, with a less average daily weight gain and a similar daily feed intake in the present study. Survival rates (81.8% from birth to weaning and 100% from weaning to slaughter) were excellent with a diet containing D. tortuosum. This result showed that ingestion of D. tortuosum contributed to the good health of rabbits. This survival rate was greater than the results of Kpodékon et al. (2009) (54.2% and 84.7% respectively with flour feed or pelleted feed, for 16-week-old rabbits). It must be noted that the high mortality rate in the study of Kpodékon et al. (2009) with flour feed can be explained by the very low content of fiber in the diet, causing enteritis and death. According to Gidenne et al. (2000), the reduction of the dietary fiber level is a major factor that increases the incidence of non-specific enteritis in the growing rabbit.

The carcass yields observed were in the range of results of Abu Hafsa and Hassan (2021) for the meat of New Zealand rabbits fed a diet supplemented with P. maximum. The muscle composition was slightly different from the results of Abu Hasfa and Hassan (2021) with less proportions of dry matter and lipids, but a similar protein proportion in the present study. These differences can be explained by the fact that we studied two muscles but Abu Hafsa and Hassan (2021) described the meat composition without any detail on the kind of muscles present in the meat.

Major sources of cholesterol in the human diet are products (egg, meat, and milk) from domestic livestock and there are concerns about its concentration because of the link between high cholesterol concentration and heart disease. The concentration of cholesterol in rabbit Semimembranosus muscle found by Dinh et al. (2011) was 80 mg/100 g of muscle, similar to the value we found in the present study for Semimembranosus from rabbits fed diet GrC or GrPan. The cholesterol concentration found by Polak et al. (2006) in rabbit Longissimus dorsi (66.7–68.6 mg/100 g of muscle) was less than the concentrations we found in the same muscle of rabbits fed GrC and GrPan. The decrease in cholesterol concentration of both muscles with the use of D. tortuosum (diet GrDes) relative to the other diets GrC and GrPan, could be due to the hypocholesterolemic effect of the plant, a consequence of its content in n-3 fatty acids, as it has been demonstrated in rats with Desmodium velutinum (Steven and Ude, 2017) and with Desmodium gangeticum (Kurian et al., 2005). The meat from rabbits fed the GrDes diet is healthy because of its low cholesterol concentration.

The fatty acid composition of rabbit meat is the reflect in the fatty acid composition of the diet. This relationship can be used to increase the human intake of fatty acids with health benefits, as n-3 essential fatty acids, which amount is considered too low, even in developed countries. Nutritionists recommend a ratio of n-6:n-3 PUFA of less than five in human diets. Today this ratio in animal products is between 10 and 15 (Kouba and Mourot, 2011). Feeding rabbits with GeDes led to an enrichment in n-3 PUFA and a reduced n-6:n-3 ratio in both muscles Semimembranosus (5.2) and Longissimus dorsi (6.1). This was due to the high amount of n-3 fatty acids in D. tortuosum. This was also observed in rabbits fed a linseed supplemented diet (Kouba et al., 2008). The use of D. tortuosum led to a healthy meat with more PUFA, especially n-3 PUFA, less n-6 PUFA, and less cholesterol.

This work shows that dry D. tortuosum mixed with a commercial-type feed did not adversely affect the rabbit’s performance. On the contrary, the reproductive and growth performance of the animals were improved. Specifically, commercial-type feed for rabbits supplemented with dried D. tortuosum had a very good galactogenic effect. The use of D. tortuosum led to a low cholesterol concentration in the rabbit muscles. Thus, D. tortuosum could be used as dried green forages to improve reproduction and lactation performance in local rabbit does and to improve growth performance and nutritional meat quality of growing rabbits.
However, our study shows that *P. maximum* did not match the excellent performance observed using *D. tortuosum* as a feed supplement. Consequently, a commercial feed should not be supplemented with only *P. maximum*. The feed cost to produce a 13-weeks-old kit was reduced with *D. tortuosum*. This leguminous fodder supplement could provide principal nutrients to rabbits and could replace at least partially, cultivated *P. maximum* in the diet of rabbits, at a very low cost.

**SUPPLEMENTARY DATA**

Supplementary data are available at Translational Animal Frontiers online.

**FUNDING**

This research did not receive any grant from funding agencies in the public, commercial, or not-for-profit sectors.

**Conflict of Interest Statement**

The authors declare that they have no conflict of interest.

**LITERATURE CITED**

Adeyemo, A. A., O. S. Taiwo, and O. A. Adeyemi. 2014. Performance and carcass characteristics of growing rabbits fed concentrate to forage ratio. *Int. J. Modern Plant Anim. Sci.* 2:33–41. http://www.modernscientificpress.com/Journals/ViewArticle.aspx?ON7biMb70/X7VmC9bFLWRSSTgX+GkwwIvT/aQihR ev4XJRMs0NSx64U8uuQ

Allain, C. C., L. S. Poon, C. S. G. Chan, W. Richmond, and P. C. Fu. 1974. Enzymatic determination of total serum cholesterol. *Clin. Chem.* 20(4):470–475.

AOAC. 2004. *Official methods of analysis*, vol. 2, 18th ed. Arlington, VA, USA: Assoc. Offl. Anal. Chem.

Delgado, R., R. Abad-Guaman, N. Nicodemus, M. J. Villamide, N. Ruiz-Lopez, R. Carabano, D. Menoyo, and J. Garcia. 2018. Effect of level of soluble fibre and n-6/n-3 fatty acid ratio on performance and carcass characteristics of growing rabbits fed concentrate to forage ratio. *Int. J. Modern Plant Anim. Sci.* 2:33–41. http://www.modernscientificpress.com/Journals/ViewArticle.aspx?ON7biMb70/X7VmC9bFLWRSSTgX+GkwwIvT/aQihR ev4XJRMs0NSx64U8uuQ

Dinh, T. T., L. D. Thompson, M. L. Galyean, J. C. Brooks, K. Y. Patterson, D. tortuosum. 2018. Effect of soluble fibre and n-6/n-3 fatty acid ratio on performance of rabbit does and their litters. *J. Anim. Sci.* 96:1084–1100. doi:10.1093/jas/skx019.

Fernández-Carmona, J., E. Blas, J. J. Pascual, L. Maertens, T. Gidenne, G. Xiccato, and J. García. 2005. Recommendations and guidelines for applied nutrition experiments in rabbits. *World Rabbit Sci.* 13:209–228. doi:10.4314/wrs.v13i1.6.

Folch, J., M. Lees, and G. H. Sloane Stanley. 1957. A simple method for the isolation and purification of total lipids from animal tissues. *J. Biol. Chem.* 226:497–509. doi:10.1016/S0021-9258(18)64849-5.

Gidenne T., V. Pinheiro, and L. Falcão e Cunha. 2000. A comprehensive approach of the rabbit digestion: consequences of a reduction in dietary fibre supply. *Livest. Prod. Sci.* 64:223–237. doi:10.1016/S0301-6226(99)00141-4.

Henaff, R., and R. Jouve. 1988. *Mémento de l'éleveur de lapins, 7ème édition*. Lempdes, editor, Association Française de Cuniculture et ITAVI, Paris, France.

Hue-Beauvais, C., E. Koch, P. Chavatte-Palmer, L. Galio, S. Chat, M. Letheule, D. Rousseau-Ralliard, F. Jaffrezic, D. Laloë, E. Aujean, et al. 2015. Milk from dams fed an obesogenic diet combined with a high-fat/high-sugar diet induces long-term abnormal mammary gland development in the rabbit. *J. Anim. Sci.* 93:1641–1655. doi:10.2527/jas.2014-1839.

INRA. 2002. *Tables de composition et de valeur nutritive des antîtres premières destinées aux animaux d'élevage*. Sauvant, D., J.M. Perez, and G. Tran, editors, INRA editions, Paris, France.

Kimsé, M., D. Soro, M. N. Bleyere, J. N. Yapi, and A. Fantodji. 2013. Apport d’un fourrage vert tropical, *Centrosemum pubescens*, en complément au granulé: effet sur les performances de croissance et sanitaire du lapin (*Oryctolagus cuniculus*). *Int. J. Biol. Chem. Sci.* 7:1234–1242. doi:10.3913/ijbcs.v7i3.29.

Kouakou, N. D. V., S. B. Mou, C. E. Angbo-Kouakou, E. Thys, N. E. Assidjo, and M. Kouba. 2016. Réduction des coûts alimentaires des lapins (*Oryctolagus cuniculus L.*). Par la distribution de l’herbe de lait (*Euphorbia heterophylla* (L.)) associée à l’herbe de Guinée (*Panicum maximum* Jacq.) Lam. en élevage semi-intensif. *J. Appl. Biosci.* 99:9739–9830. doi:10.4314/jab.v99i1.3.

Kouba, M., F. Benatmane, J. E. Blochot, and J. Mourot. 2008. Effect of a linseed diet on lipidoxidation, fatty acid composition of muscle, perirenal fat, and raw and cooked rabbit meat. *Meat Sci.* 80:829–834. doi:10.1016/j.meatsci.2008.03.029.

Kouba, M., and J. Mourot. 2011. A review of nutritional effects on fat composition of animal products with special emphasis on n-3 polyunsaturated fatty acids. *Biochimie.* 93:13–17. doi:10.1016/j.biochi.2010.02.027.

Ludwigczak, A., J. Skladanowska-Baryza, B. Kuczynska, and E. Dell-é. 2006. Rabbit milk: a review of isolation and purification of total lipids from animal tissues. *Lact. World* 13:209–228. doi:10.4995/wrs.2006.565.

Maertens, L., F. Lebas, and Z. Szendrö. 2006. Rabbit milk: a review of productive output in the guinea pig. *J. Exp. Zool. A: Ecol. Genet.* 317:24–31. doi:10.1002/jez.714.

Maertens, L., T. Pays-Tropp, S. B. Adjiadjemian, Z. Diarrassouba, K. R. N’Guessan, and M. Kouba. 2015. Effet de la granulation sur les performances de croissance, l’efficacité alimentaire et la viabilité des lapereaux en condition d’élevage tropical. *Revue Elev. Méd. Vét. Pays Trop.* 62:75–80. doi:10.19182/remvt.10097.

Mourat, G. X., A. S. Philip, and T. Vargese. 2005. Effect of aqueous extract of the *Desmodium gangeticum* DC root in the severity of myocardial infarction. *J. Ethnopharmacol.* 97:457–461. doi:10.1016/j.jep.2004.11.028.

Morrison, W. R., and L. M. Smith. 1964. Preparation of fatty acid methyl esters and dimethylacetals from lipids with boron trifluoride. *J. Lipid Res.* 5:600–608. doi:10.1016/S0022-2275(20)40190-7.
Polak, T., L. Gasperlin, A. Rajar, and B. Bozidar Zlender. 2006. Influence of genotype ines, age at slaughter and sexes on the composition of rabbit meat. *Food Technol. Biotechnol.* 44:65–73. https://hrcak.srce.hr/file/161715

Richard, D., H. Guerin, D. Friot, and N. Mbaye. 1990. Teneurs en énergies brute et digestible de fourrages disponibles en zone tropicale. *Revue Élev. Méd. vét. Pays trop.* 43:225–231. doi:10.19182/remvt.8858.

Rommers, J., R. Meijerhoft, J. Noordhuizen, and B. Kemp. 2002. Relationships between body weight at first mating and subsequent body development, feed intake, and reproductive performance of rabbit does. *J. Anim. Sci.* 80:2036–2042. doi:10.2527/2002.8082036x.

Salama, W. A., and E. H. Abo El-Azayem. 2018. Reproductive and physiological response of New Zealand white rabbits does fed on discarded palm fronds. *Egyptian J. Rabbit Sci.* 28:351–370. doi:10.21608/ejrs.2018.44315.

Steven, P. E., and C. M. Ude. 2017. Hypolipidaemic effect of aqueous extract of *Desmodium velutimum* leaf on albinos Wistar rats. *Adv. Med. Plant Res.* 5:47–50. doi:10.30918/AMPR.54.17.024.

Toleba, S. S., M. Dahouda, S. D. Vidiannagni, H. Sina, U. Natonnagnon, A. Harouna, A. D. Adenile, N. S. I. Anagonou, and L. Baba-Moussa. 2017. Ingestions alimentaires et performances de production et de reproduction des lapines (*Oryctolagus cuniculus*) gestantes nourries avec des aliments contenant des feuilles de neem (*Azadirachta indica*). *Eur. Sci. J.* 13:82–100. doi:10.19044/esj.2017.v13n15p82.

Webster, T. M., and J. Cardina. 2004. A review of the biology and ecology of Florida beggaweed (*Desmodium tortuosum*). *Weed Sci.* 52:185–200. doi:10.1614/ws-03-028r.