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Simulation and Optimization of Available Local Feed Resources for Dairy Cattle in Burkina Faso

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Abstract: The poor quality of natural pastures in the dry season does not make it possible to meet dairy cows' requirements for milk production in Burkina Faso and in most West African countries. Therefore, it is urgent to find an alternative by developing a full diet from locally available ingredients. The objective was to determine a diet for dairy cattle based on locally available ingredients in the peri-urban area of Ouagadougou. A progressive methodology was used. Thus, a survey was conducted ontoonton 30 dairy farms. This survey was followed by chemical analysis, for which the most dominant forage and concentrate ingredients were selected. Secondly, the recording of milk and on-farm ingredient use was also carried out using Op-Ration software (Op-Ration version V3.4.5.0) in order to compare and determine the most suitable diets. The data from the survey were subjected to descriptive statistics using SPSS version 20. Those from chemical analysis, milk recording, and ingredient assessment on the farm were subjected to a statistical method using the software Minitab version.18.1.0.0 setup. The results showed two dominant forage species, Sorghum (84.85%) and *Pennisetum pedicellatum* (90.91%), and two dominant concentrates, corn bran (32%) and cottonseed meal (26%), used by dairy farmers. From these ingredients and simulating the requirements of 400 kgPV$^{0.75}$ of lactating cows, a diet assessment was carried out at early, middle, and end lactation. The results showed that at the beginning of lactation, the diet consisted of 6.73 kg of forage and 6.59 kg of concentrate for 13.5 L as the main objective of milk production. The diet for mid-lactation was 8 kg of forage and 6.5 kg of concentrate for 15.5 L per day and 5.7 kg of forage and 3.8 kg of concentrate for the end of lactation. The results of this study show that it is possible to manufacture a complete ration for dairy cows at different stages of lactation from locally available forages and concentrates in the peri-urban area of Ouagadougou. This type of method could be applied to other regions from local forages and concentrates for milk production.

Keywords: survey; ingredients; diet calculation; cow; milk

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1. Introduction

West Africa's demand for dairy products is growing significantly due to sustained population growth and the emergence of a middle class [1]. In Burkina Faso, between 1970 and 2010, this demand rose from 4.1 to 21.6 million tons of milk equivalent per year [2]. Despite the country's significant dairy potential (9.7 million cattle, 11.5 million sheep, and 10.7 million goats) [3], Burkina Faso nevertheless continues to spend over 14 billion CFA each year on milk and dairy product imports. In addition, livestock farming faces enormous difficulties, especially in terms of animal feed supplies, due to its extensive nature, which

limits production. Indeed, livestock feeding relies essentially on the exploitation of natural pastures [4]. Thus, to feed dairy cows well, farmers should have constant access to pasture, forage, and feed in sufficient quantities and of good quality [5]. Furthermore, in the dry season, the poor quality of grazed resources, whether crop residues left in the field or spontaneous rangeland vegetation, leads to a drop in production performance and a notable fall in milk production [6–8]. To overcome animal feed constraints, peri-urban livestock farmers adopt several strategies to feed their dairy herds, including exploiting the rangelands still available at the periphery of towns, supplementing what is available on the farm, and growing fodder crops. Despite the interest shown by livestock farmers in agro-industrial by-products (AIBP), their large-scale use is hampered by their low availability and high cost, due to the remoteness of the areas where these products are produced and speculative practices of traders [9]. In this context, to help farmers achieve their milk production objectives, testing options for improving feed by making the most of locally available resources is an appropriate option. However, how can a rationing technique based on these ingredients be successfully implemented? In fact, rationing consists of establishing rations by calculating the quantities of feed with known nutritional values (extracted from feed tables) that will meet the animals' needs for a given production [10]. However, depending on the types of feed used daily by producers, it is possible to group them into batches corresponding to rations. There are also software programs available today that allow balanced ration calculation from a large number of available feeds. Accordingly, it is imperative to ask how suitable rations based on locally available feed ingredients can be determined to promote the rational operation of dairy farms in Burkina Faso. Hence, the aim of the present study was to simulate an optimized ration for feeding dairy cows in the peri-urban area of Ouagadougou (Burkina Faso) based on locally available feed ingredients. Then, locally available feed ingredients from a dairy farm and a comparison will be analyzed, followed by ration simulation using rationing software and quantification measurement.

2. Materials and Methods

2.1. Farm Description

The study was carried out in the peri-urban area of Ouagadougou in two regions with six peri-urban communes (Figure 1). These were the communes (districts) of Koubri, Pabré, Saaba, Tanghin Dassouri, and Komsilga in the Centre region, and the commune of Loumbila in the Plateau Central region. According to the Second Nationwide Survey on Livestock (ENEC II) [11], this area is the country's leading dairy basin, although it is hosting a large number of dairy herds from traditional and semi-improved farms.

The farms were selected through the extension agents in charge of the livestock farming technical support zones. Thirty dairy farms were selected and distributed as follows: fifteen traditional farms and fifteen semi-improved farms, considering five farms per commune. The selection criteria were to have a traditional or semi-improved dairy farm and lactating cows for experimentation following the survey.

2.2. Questionnaire Design

Two primary points were covered in a structured questionnaire. The first covered a brief overview of the farm (name and surname of the farmer or companies, age and years of experience in milk production) and the zootechnical parameters of the animals (breeds used, number of lactating cows in lactation, etc.). The second focused on feed management, including the feed ingredients used and any difficulties encountered.

2.3. Survey Procedure and Collection of Animal Feed Ingredients

The survey was conducted in two phases. The first phase laps from December 2022 to January 2023. This involved discussions with the herdsman and/or the farm owner at the said farm. A total of thirty farms were involved, including fifteen traditional farms and fifteen semi-improved farms. The second phase involved a smaller number of farmers, ten in all, and consisted of identifying and recording the zootechnical parameters of the

dairy animals. The information and individual performances of each cow were recorded on a sheet. On the farms surveyed, various ingredients used to feed the dairy cows were sampled. Each sample was individually wrapped in a plastic bag, packaged, and labeled for laboratory analysis.

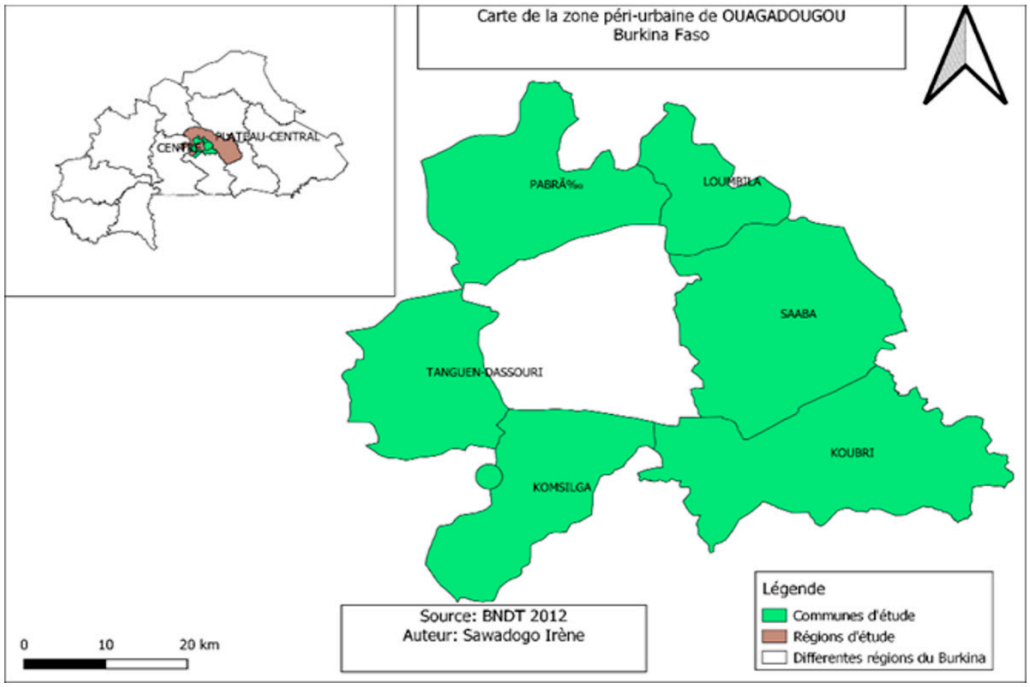


Figure 1. Map of the study area (BNTD).

2.4. Chemical Analysis of Various Animal Feed Ingredients

For the chemical analyses of the various animal feed ingredients, the chemical analysis methods used were those of the official methods of analysis of the Association of Official Analytical Chemists (AOAC) [12]. Bromatological analyses were carried out at the Animal Nutrition Laboratory of the Animal Production Department at the Center for Environmental, Agricultural, and Training Research (CREAF) in Kamboinsé (Ouagadougou, Burkina Faso). They concerned the various products inventoried by farmers, and involved the determination of parameters such as dry matter (DM) obtained by drying at +105 °C in an oven for 24 h; mineral matter (MM) or ash determined by passing the dry sample through an oven set at +550 °C for 3 h; organic matter (OM) obtained by the difference between DM and ash (MM) (OM = DM−MM); Total Nitrogen Matter (TNM) obtained by the classic method of Kjeldahl: mineralization followed by distillation to obtain the nitrogen percentage of the sample. Crude protein (CP) was estimated by applying the coefficient 6.25 conventionally used for these products to the percentage of nitrogen (%N); Gross Cellulose (BC) was determined using the Weende method, one of the most widely used methods for determining plant cell wall constituents. The walls (NDF, ADF, ADL) were determined using the method of [13], which isolates the total components of the cell wall.

2.5. Statistical Analysis of Survey Data and Bromatological Analysis Data

Data collected during the farmer survey were coded, entered, and processed using SPSS (Statistical Package for Social Science) version 20 software, using descriptive statistics methods. As for the data from the chemical analysis of feed and raw milk, descriptive statistics were produced using Minitab software version 18.1.0.0 setup. This time, the variables were density, fat content (FC), protein content (PC), lactose (L), dry matter (DM),

and quantity of milk produced per cow, expressed as a percentage. Results were expressed as mean ± standard deviation.

2.6. Diet Formulation and Rationing Methodology Based on Survey Data

2.6.1. Diet Determination (Formulation or Calculation)

Op-Ration version V3.4.5.0 (trial version, formally purchased under number 202306131) was used as a ruminant rationing software that integrates both a technical approach and the use of elaborate ruminant nutrient data. This tool was used to create, calculate, and analyze optimized diets for lactating cows at different physiological stages. Collective diets and/or individual diets, as well as diets for dry pregnant cows, were thus created at the onset and mid lactation.

2.6.2. Pre-Setting

Before determining a ration for dairy cows, a few requirements need to be fulfilled. These include the live weight of the animals, which was estimated using a barometric tape as used by [14] on the basis of its correlation with thoracic girth. Eight (08) cows were included in this study: three (03) early-lactation cows, three (03) mid-lactation cows, and two dry pregnant cows. Three diets were developed, taking into account the different physiological stages of early, mid, and late lactation (dry and pregnant cows). Finally, based on surveys and the bromatological analysis of feed ingredients, four main ingredients (i.e., the most dominant, available in the study area) were selected for the preparation of diets based on local feeds, i.e., two ingredients for forage and two ingredients for concentrates. These were *Sorghum bicolor* (*S. bicolor*) straw, *Penissetum pedicellatum* straw (natural forage), cottonseed cake, and maize bran.

2.6.3. Dietary Assessment Methodology

Following surveys and the collection of local ingredients used to feed dairy cows, a ration was determined based on the average quantities of the various ingredients in the theoretical diets (calculated on the basis of survey data). The average values of these various ingredients were compared with those distributed by the herdsmen in order to find a balance and suggest an optimized diet according to the different stages of lactation on a semi-improved farm located in Pabré (Kadiogo province, Burkina Faso). Concentrated feed was distributed twice a day during morning milking (6:30 a.m.) and evening milking (4:00 p.m.), and the cows were grazed for 8 h each day and fed free choice hay one day a week (the herdsman's the rest of the day).

2.6.4. Methods for Determining the Nutritional Value of Ingredients

In addition to the bromatological values of the four dominant feed ingredients, nutrient values such as PDIE, PDIN, PDIA, and UFL were calculated using the formulas in the dairy cow diet table based on the formulas below [15]. These results enabled us to set our milk production target in the menu bar of the Op-Ration version V3.4.5.0. PDIA = crude protein × [1.11 (1 − DT)] × dr with PDIA = digestible protein in the small intestine from feed in g/kg DM; MAT = crude protein in g/kg DM; DT = theoretical degradability of feed crude protein in the rumen in %; dr = actual digestibility of dietary amino acids in the small intestine in %. PDIN = PDIA + PDIMN where PDIN = digestible protein in the intestine from available nitrogen in g/kg DM; PDIA = protein digestible in the intestine from feed in g/kg DM, equation given above. PDIMN = MAT × [1-1, 11 (1 − DT)] × 0.9 × 0.8 × 0.8 with PDIMN = digestible proteins in the gut of microbial origin, limited by degradable nitrogen in g/kg DM; MAT = crude protein in g/kg DM; DT: theoretical degradability in % of meat and q = EM/EB = EM concentration of feed. PDIE = PDIA + PDIME with PDIE = digestible protein in the intestine from available energy in g/kg DM; PDIA = protein digestible in the intestine from food in g/kg DM. PDIME = MOF × 0.145 × 0.8 × 0.8 with PDIME = protein digestible in the intestine thanks to available energy (g/Kg DM); MOF = fermentable organic matter = MOD − [MAT × (1 − DT)] where

MOD = digestible organic matter = MO × dMO; MO = organic matter in g/kg DM; dMO = digestibility of organic matter in %; MAT = total nitrogenous matter in g/kg DM, DT = theoretical degradability in %. UFL/kg DM = ENL/1700. With: ENL = net energy for lactation = 1700 Kcal. ENL = EM × Kl in kcal/kg DM. With EM = metabolizable energy in kcal/kg DM; Kl = yield of EM in EN for milk production; Kl = 0.60 + 0.24 (q − 0.57) where q = EM/EB = EM concentration of feed. UFV/kg DM = ENEV/1820 with ENEV = net energy for maintenance and meat production = 1820 Kcal; ENEV = EM × Kmf in kcal/kg DM, where Kmf = (Km × Kf × 1.5)/(Kf + 0.5 Km), Km = 0.287 q + 0.554 = efficiency of EM in EN for maintenance, Kf = 0.78 q + 0.006 = yield of EM in EN for meat production and q = EM/EB = EM concentration of feed.

2.6.5. Optimized Diets

The values of the different average quantities of feed ingredients (forage and concentrate) and the expected milk quantity of our three diets (formulated theoretical diets, on-farm diets distributed, and diets from Op-Ration version V3.4.5.0) were compared. The aim was to find an optimized ration to maintain and/or increase milk production on the various peri-urban farms in the city of Ouagadougou (Burkina Faso).

2.7. Monitoring of Milk Production on Farm

2.7.1. Milking Process

Cows were hand-milked. Milkers cleaned their hands before each milking. The calves were used to stimulate milk ejection for all the cows. Each cow's milk was collected in an individual bucket with a maximum milking time of around ten minutes. Milk quantity recording and raw milk sampling were carried out after morning and evening milking. The quantity of milk per cow was measured using a graduated plastic cup (2000 ± 10 mL). This estimate did not take into account the milk consumed by the calf. The daily quantity of each treatment per cow was made up of the sum of the milk produced in the morning at 6:30 a.m. and in the evening at 4:00 p.m. After each milking, a milk sample was taken from each cow twice a month in a labeled 20-milliliter plastic bottle and stored in a cooler containing ice cubes to maintain the temperature below +10 °C. The samples were transported in a cooler to the laboratory for chemical analysis. In total, 72 milk samples were collected during six months from July to December 2023.

2.7.2. Milk Composition Chemical Analysis and Statistical Analysis of Milk's Chemical Data

The fat (F), protein (P), lactose (L), dry matter (DM), and density of raw milk samples were determined using the infrared spectroscopy method (Dairy Milk Analyzer, Miris AB, 2001, Uppsala, Sweden). All samples were analyzed no more than 48 h after collection. Excel 2016 software was used to enter and process data relating to the milk chemical analysis. Analysis of variance (ANOVA) was used Mulitab.18.1.0.0 setup. The variables were density, fat content (FC), protein content (PC), lactose (L), dry matter (DM), and quantity of milk produced per cow, expressed as a percentage. Results were expressed as mean ± standard deviation. Variable means were compared using Fisher's test, and differences were considered significant at the $p < 0.05$ probability level.

3. Results

3.1. Feed Ingredient Resources Used by Peri-Urban Farms of Ouagadougou

The screening of local feed used in the dairy cattle feeding system showed two types of ingredients: the forage as the feed base, in which there are ligneous species (*P. reticulatum* pod), *grass species* (*A. gayanus*, *P. pedicellatum*, *B. ruziziensis*, *P. maximum*, *Maralfalfa* sp., *M. sativa*), and crop residue products (maize and sorghum silages, rice, maize, sorghum straw, and soy bean hay). Among those species, sorghum stem and *P. pedicellatum* straw are the most dominant forages for dairy cattle with percentages of 84.85% and 90.91%, respectively. The second group of ingredients includes cottonseed cake, soya bean cake, maize bran,

maize flour, sugar molasses, wheat bran, sorghum bran, maize, and sorghum brewer grain, SOFAB (livestock feed production company in French, Ouagadougou, Burkina Faso) concentrates. Maize bran, cottonseed cake, and maize flour were the most dominant concentrates used in the dairy cattle feeding system at percentages of 32%, 26%, and 22%, respectively.

3.2. Feed Ingredients Chemical Composition

The chemical compositions of forages and concentrates according to the type of ingredient are in Tables 1 and 2. Table 1 shows the ingredients that are mostly used with high dry matter content (95–98%) and the average between 2 and 10% for the crude protein content. For the same ingredients, the crude fiber content for the majority of forage species was between 20 and 34%, except for maize silage; *T. dolonepfolius* and *Piliostigma* showed lower content of less than 15%. All species showed higher NDF and ADF contents (Table 1). However, the ADL content of the same species was between 5 and 10% with a lower average for maize silage. The mineral content was lower than 12% for all species.

Table 1. Chemical composition of forages from survey.

Forage Types	%DM	%MM	%CP	%CF	%NDF	%ADF	%ADL
Maize stem	97.45 ± 0.07	10.01 ± 0.06	3.84 ± 0.5	24.55 ± 0.11	63.78 ± 0.36	34.77 ± 0.69	8.51 ± 0.56
Sorghum stem	96.85 ± 0.14	6.12 ± 0.11	2.78 ± 0.5	27.59 ± 0.33	66.6 ± 0.16	35.84 ± 0.03	10.25 ± 0.7
Sorghum leaves	96.06 ± 0.04	8.66 ± 0.06	1.93 ± 0.74	21.66 ± 0.29	52.95 ± 0.04	27.12 ± 0.07	5.14 ± 0.39
Soybean pod	96.28 ± 0.02	5.46 ± 0.2	5.55 ± 0.97	33.45 ± 0.58	49.3 ± 00	26.46 ± 0.16	7.27 ± 0.01
P. pedicellatum Straw	98.7 ± 0.42	5.29 ± 0.04	1.57 ± 0.24	33.56 ± 0.13	75.55 ± 0.5	45.93 ± 0.4	10.62 ± 0.35
Maize silage	96.9 ± 0.28	5.59 ± 0.11	5.74 ± 0.77	11.13 ± 0.33	43.6 ± 0.04	16.05 ± 0.04	2.05 ± 0.04
Sorghum seed head	96.81 ± 0.05	4.58 ± 0.13	7.13 ± 0.19	18.9 ± 0.08	64.2 ± 0.1	29.2 ± 0.08	9.31 ± 0.22
Maralfalfa	97.29 ± 0.0	11.42 ± 0.02	3.66 ± 0.17	24.76 ± 0.08	65.43 ± 0.11	30.46 ± 0.27	8.14 ± 1.03
Sorghum silage	96.39 ± 0.05	10.18 ± 0.14	10.65 ± 0.16	25.08 ± 0.08	63.9 ± 0.19	33.91 ± 0.27	5.5 ± 0.24
Soybean hay	95.59 ± 0.01	6.85 ± 0.11	6.44 ± 0.52	29.44 ± 0.79	57.26 ± 0.04	38.62 ± 0.02	10.56 ± 0.24
T. dolonepfolius hay	96.75 ± 0.06	10.08 ± 0.0	9.25 ± 0.25	14.2 ± 0.13	39.12 ± 1.05	26.93 ± 0.04	4.82 ± 0.16
A. gayanus hay	97.44 ± 0.1	6.11± 0.1	2.44 ± 0.5	28.75 ± 0.19	72.83 ± 0.28	37.55 ± 0.57	10.23 ± 0.35
Piliostigma pod	96.64 ± 0.02	5.73 ± 0.05	7.68 ± 0.01	13.04 ± 0.06	53.49 ± 0.04	42.53 ± 0.35	22.17 ± 0.08
P. pedicellatum hay	96.43 ± 0.1	10.78 ± 0.67	5.73 ± 0.21	29.47 ± 0.53	69.53 ± 1.15	36.27 ± 0.26	7.165 ± 0.37

DM = dry matter; MM = mineral matter; CP = crude proteins; CF = crude fiber; NDF = neutral detergent fiber; ADF = acid detergent fiber; ADL = acid detergent lignin. Results are expressed as mean percentage (%) ± standard deviation.

Table 2. Chemical composition of concentrates from survey.

Types of Concentrates	%DM	%MM	%CP	%CF	%NDF	%ADF	%ADL
Sogobalo	93.15 ± 0.0	7.13 ± 0.05	16.04 ± 0.03	4.97 ± 0. 08	34.81 ± 0.06	38.62 ± 0.02	10.56 ± 0.24
SOFAB milk diet	97.95 ± 0.05	10.84 ±0.11	17.75 ± 0.4	6.46 ± 0.05	44.41 ± 0.54	13.85 ± 0.15	9.15 ± 0.01
Cottonseed cake	97.01 ± 0.05	4.54 ± 0.08	24.33 ± 0.42	19.23 ± 0.11	56.63 ±1.06	34.87 ± 0.7	2.59 ± 0.14
Maize spent grain	95.07 ± 0.06	4.79 ± 0.01	25.74 ± 0.45	12.75 ± 0.16	57.33 ± 1.34	20.35 ± 0.0	0.02 ± 0.007
Sorghum brewers	93.82 ± 0.01	4.09 ± 0.02	25.46 ± 0.02	13.14 ± 0.11	60.15 ± 0.26	21.06 ± 0.01	1.89 ± 0.2
Maize flour	93.55 ± 0.04	3.61 ± 0.08	10.12 ± 1.01	1.77 ± 0.33	31.19 ± 0.04	5.04 ± 0.14	0.72 ± 0.04
Soybean flour	95.03 ± 0.06	5.46 ± 0.06	6.75 ± 0.29	8.1 ± 0.15	23.14 ± 1.2	9.94 ± 0.08	1.11 ± 0.11
Lacto, Kossodo	97.54 ± 0.04	9.69 ± 0.07	15.52 ± 1.58	10.44 ± 0.08	53.36 ± 0.25	17.11 ± 0.3	4.76 ± 0.75
Maize seed	91.26 ± 0.06	1.125 ± 0.01	7.15 ± 0.25	0.38 ± 0.02	20.79 ± 0.22	2.44 ± 0.18	1.65 ± 0.38
Soybean Pougmbiga	95.53 ± 0.11	8.42 ± 0.1	9.95 ± 0.23	25.72 ± 0.37	49.9 ± 1.15	33.45 ± 0.02	7.92 ± 0.35
Maize bran	93.06 ± 0.14	4.99 ± 0.05	9.42 ± 0.48	1.97 ± 1.87	35.88 ± 0.96	7.93 ± 0.52	8.51 ± 0.48

DM = dry matter; MM = mineral matter; CP = crude proteins; CF = crude fiber; NDF = neutral detergent fiber; ADF = acid detergent fiber; ADL = acid detergent lignin, SOFAB = livestock feed production company in French. Results are expressed as mean percentage (%) ± standard deviation.

3.3. Nutritive Values of the Dominant Feed Ingredients

Data from the survey showed four dominant feed ingredients, which were two forages and concentrates. The ingredients were mainly sorghum and *P. pédicellatum* straws, maize bran, and cottonseed cake. On the farm, the percentage was 84.85%, 90.91%, 69.7%, and 87.88%, respectively, in the feeding system. Those ingredients were used as the base of the diets for the dairy cattle. The crude protein content for sorghum and *P. pédicellatum*

straws, cottonseed cake, and maize bran were 2.78%, 1.57%, 24.33%, and 9.42%, respectively (Table 3). The current dominant ingredients have been used to make diets for dairy cattle.

Table 3. Nutritive values of dominants ingredients used by dairy farmers.

Ingredients	Using Percentage	%DM	%CP	%CF	PDIE (g/kg)	PDIN (g/kg)	PDIA (g/kg)	UEL (kg)
Sorghum straw	84.85	96.85	2.78	27.59	9.67	17.54	8.64	1.21
P. pedicellatum straw	90.91	98.70	1.57	33.56	5.46	9.91	4.87	1.28
Cottonseed cake	87.88	97.03	24.33	19.22	175.78	177.41	121.48	---
Maize bran	69.70	93.06	9.42	1.97	102.50	64.82	38.75	---

DM = dry matter; CP= crude proteins; CF = crude fiber; PDIN = digestible protein in the intestine from available nitrogen in g/kg DM; PDIE = digestible protein in the intestine from available energy in g/kg DM; PDIA = protein digestible in the intestine from feed in g/kg DM; milk dimensions unit (UEL = unite encombrement milk).

3.4. Comparison of Dairy Cattle Diets Requirements

Survey and on-farm measurement data have been compared (Table 4). The survey data showed the total dry matter (DM) daily consumption, 10.75 ± 1.42 kg for forage and 4.18 ± 2.29 kg for concentrates for a milk yield of 6.75 ± 4.3 L. The current data are based on dairy farmers' declarations. When the same type of data were recorded from the dairy farm, the average values were 11.58 ± 2.27 kg DM for forages and 9.53 ± 1.84 kg DM for concentrates for a daily cow milk yield of 7.6 ± 3.91 L.

Table 4. Feed ingredients amount and dairy cattle daily milk yield.

Data Source	Forage Quantity/Cow/Day	Concentrate Quantity/Cow/Day	Milk Yield/Cow/Day
From survey	10.75 ± 2.97 kg DM ^{a}	4.18 ± 2.29 kg DM ^{a}	6.75 ± 4.37 ^{b} kg of milk
From measurement	11.58 ± 2.27 kg DM ^{a}	9.53 ± 1.84 kg DM ^{b}	7.6 ± 3.91 ^{b} kg of milk

DM: dry matter, kg: kilogram. For each variable, the values with the same letters are not different at the threshold $p > 0.05$ and those with different letters ^{a} and ^{b} are significantly different at the threshold $p < 0.05$.

3.5. Diet Suggestion for Dairy Cow of a Body Weight of 400 kg$^{0.75}$

Table 5 shows total dry matter according to lactation stages, DM intake, and the body conditions score (BCS). Dairy cow total DM intake was 13.3 kg, 14.5 kg, and 9.5 kg for early, mid, and end lactation, respectively. At the same time, the fluctuation in BCS was −0.46, −0.22, and +0.45 according to the course of lactation. There was a good balance between the milk footprint unit and the degradable nitrogen in small intestine and the energy degradable proteins in the small intestine were in good balance with the milk footprint unit, with an average of 123.6 and 113.3, respectively.

Table 5. Requirements and milk production potential for dairy cow with 400 kg$^{0.75}$ BW.

Lactation Stages	DM (kg)	% DM Intake	Excepted Milk (kg/Day)	Gap Body Conditions Score (pt)	PDIN/UFL	PDIE/UFL
Early lactation	13.3	100	13.5	−0.46	123.6	123.6
Mid lactation	14.5	100	15.5	−0.22	113.3	113.3
End lactation and Dry Pregnant cows	9.5	100		+0.45		

DM = dry matter; PDIN/UFL = digestible protein in the intestine from available nitrogen in g/kg DM over the milk dimensions unit (unité encombrement lait), PDIE/UFL = digestible protein in the intestine from available energy in g/kg DM over the milk dimensions unit (unité encombrement lait). Forage and concentrate DM calculated by OP Ration software.

Table 6 shows the amount of DM according to forage and concentrates. For forage, the DM (kg) was 6.73, 8.0, and 5.7 kg for early, mid, and end lactation, respectively. For concentrates, the amount of DM was 6.59, 6.5, and 3.8 kg. The expected milk yield for the respective amount of DM was 13.5, 15.5, and 0.0 kg. During the end of lactation, the cow was dry and not giving milk at all. The feed intake was higher during the early and mid-lactation and corresponded also to high milk yield. This calculation was conducted from data collected from locally available forages and concentrates in the peri-urban area of Ouagadougou (Burkina Faso).

Table 6. Ingredients amount and milk yield calculated from Op-Ration software.

Lactation Stages	Forages DM (kg)	Concentrates DM (kg)	Expected Milk Yield (L)
Early	6.73	6.59	13.5
Mid	8.0	6.5	15.5
End	5.7	3.8	0.0

3.6. Amount of Ingredient Comparison Between On-Farm and Survey

In order to be able to suggest an optimum diet for the peri-urban area of Ouagadougou in Burkina Faso, the number of diets' ingredients was assessed by survey, on-farm measurement, and diet software calculation based on the nutritive value of local available feed ingredients used by dairy farmers. Table 7 shows for forage amount, 10.75 ± 1.42 kg DM, for concentrates, 4.18 ± 2.29 kg DM, and from survey data for milk yield 6.75 ± 4.3 L per day. The results from on-farm measurements for concentrates indicate for forages and concentrates, 11.58 ± 2.27 kg DM and 9.53 ± 1.84 kg DM, respectively, for a daily milk yield of 7.6 ± 3.91 L. Op-Ration calculated out the total amount of dry matter for forages, 6.81 ± 1.15 kg, concentrates, 5.63 ± 1.58 kg, and for daily milk yield per cow 14.5 ± 1.41 L.

Table 7. Comparison of diet ingredient amounts from survey, measurement data, and Op-Ration-calculated data.

Data Origin	Forage DM/Cow/Day (kg)	Concentrate DM/Cow/Day (kg)	Milk Yield/Day (L)
Survey	10.75 ± 2.97 ^{a}	4.18 ± 2.29 ^{a}	6.75 ± 4.37 ^{a}
Measurements	11.58 ± 2.27 ^{a}	9.53 ± 1.84 ^{b}	7.6 ± 3.91 ^{a}
Op-Ration	6.81 ± 1.15 ^{b}	5.63 ± 1.58 ^{a}	14.5 ± 1.41 ^{b}

In the same column, the data average dm amount and milk yield with the same alphabetic letters are not different ($p > 0.05$) and the data with different alphabetic letters are different at $p < 0.05$.

3.7. Average Chemical Composition of Raw Milk from Dairy Farms

During the measurements of diets' ingredients and to be able to suggest a diet for dairy cows, milk recording was conducted at the same time. The results showed that milk yield was different from cow to cow. All cows significantly produced more milk during morning milking compared to evening milking ($p < 0.05$). There was no variation in milk proteins, lactose contents, and milk density between morning and evening milking. Milk DM content showed significant variation between days and months during the recording time. Milk fat content was significantly higher in evening milk than in morning milk (Table 8). When milk yield was higher, fat content was lower and when milk yield was lower, fat content was higher.

During the first three months, July, August, and September 2023, milk fat content significantly decreased to a minimum average at the end of September and early October. After that, milk fat content significantly increased between October and December 2023. At the same time, milk protein did not change much regarding the milk yield recorded (Figure 2).

Table 8. Morning and evening milk yield and composition for six lactating cows during the recording period.

Cow ID	Milking Time	Milk Yield (L)	%Fat	%Protein	%Lactose	%Dry Matter	Density
VA	M	4.02 ± 0.17 ^{b}	7.41 ± 2.52 ^{b}	3.94 ± 0.61 ^{b}	4.09 ± 0.87 ^{b}	15.59 ± 3.21 ^{b}	1.03 ± 0.004 ^{b}
	E	2.72 ± 0.13 ^{b}	8.56 ± 2.38 ^{b}	4.29 ± 0.57 ^{b}	3.55 ± 0.71 ^{b}	16.91 ± 3.16 ^{b}	1.03 ± 0.004 ^{b}
VB	M	2.10 ± 0.24 ^{cd}	9.80 ± 3.65 ^{cd}	4.66 ± 1 ^{cd}	4.08 ± 1.1 ^{cd}	13.57 ± 2.1 ^{cd}	1.03 ± 0.004 ^{cd}
	E	1.49 ± 0.21 ^{c}	7.59 ± 2.41 ^{c}	4.51 ± 0.60 ^{c}	3.98 ± 1.09 ^{c}	15.5 ± 3.78 ^{c}	1.03 ± 0.004 ^{c}
VC	M	3.79 ± 0.43 ^{b}	7.96 ± 3.05 ^{b}	4.36 ± 0.64 ^{b}	4.51 ± 0.90 ^{b}	17.38 ± 3.8 ^{b}	1.03 ± 0.004 ^{b}
	E	2.51 ± 0.26 ^{b}	8.22 ± 2.81 ^{b}	4.74 ± 0.60 ^{b}	4.29 ± 0.89 ^{b}	17.93 ± 3.66 ^{b}	1.03 ± 0.004 ^{b}
VD	M	1.25 ± 0.1 ^{d}	6.50 ± 2.22 ^{d}	4.36 ± 0.64 ^{d}	4.03 ± 0.89 ^{d}	16.30 ± 2.82 ^{d}	1.03 ± 0.003 ^{d}
	E	0.65 ± 0.80 ^{d}	8.72 ± 3.05 ^{d}	4.11 ± 0.75 ^{d}	4.10 ± 0.86 ^{d}	18.06 ± 3.67 ^{d}	1.03 ± 0.004 d
VE	M	2.57 ± 0.38 ^{c}	10.19 ± 4.39 ^{c}	5.34 ± 1.11 ^{c}	3.97 ± 1 ^{c}	16.79 ± 4.81 ^{c}	1.03 ± 0.004 ^{c}
	E	1.81 ± 0.26 ^{c}	12.26 ± 4.7 ^{c}	5.75 ± 1.02 ^{c}	3.94 ± 0.95 ^{c}	22.68 ± 5.81 ^{c}	1.03 ± 0.004 ^{c}
VF	M	7.05 ± 0.36 ^{a}	5.83 ± 2.29 ^{a}	3.97 ± 0.57 ^{a}	4.11 ± 0.88 ^{a}	16.79 ± 4.81 ^{a}	1.03 ± 0.004 ^{a}
	E	4.68 ± 0.31 ^{a}	7.46 ± 2.83 ^{a}	4.21 ± 0.69 ^{a}	3.99 ± 0.85 ^{a}	17.09 ± 3.61 ^{a}	1.03 ± 0.003 ^{a}

M = morning; E = evening. For each parameter, the average values with the same alphabetic letters are not different and the average values with a different alphabetic letter are different at $p < 0.05$.

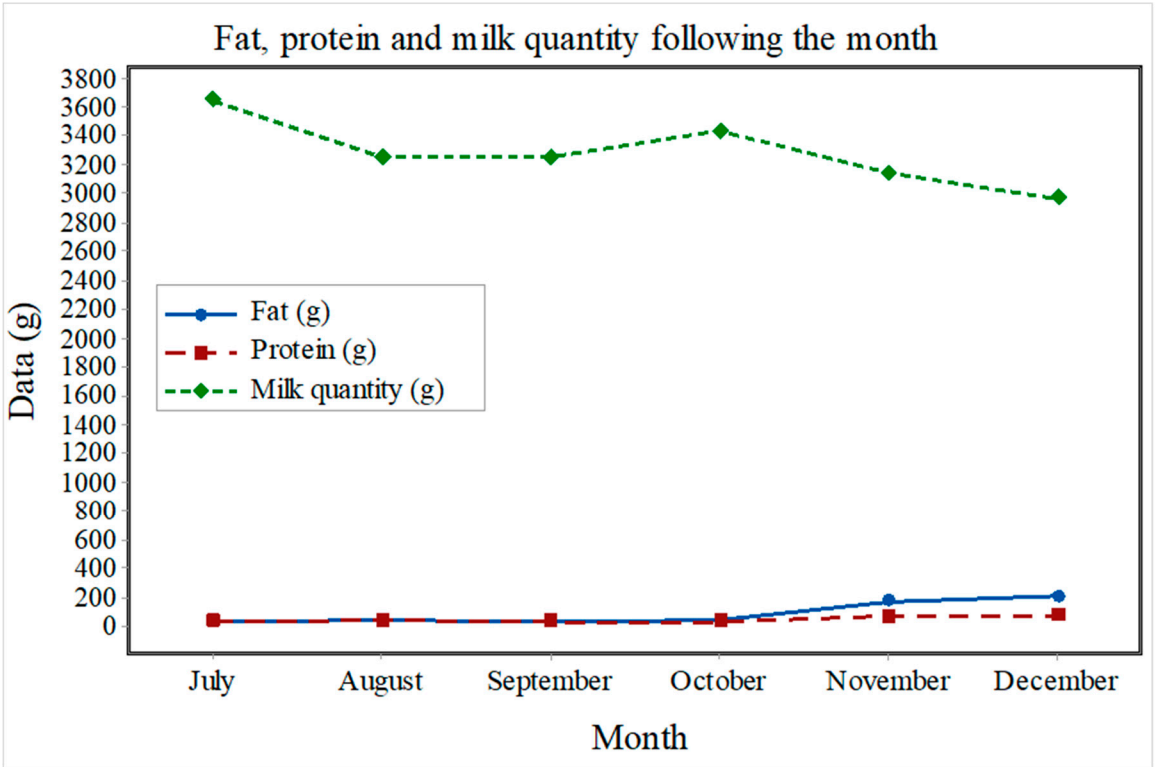


Figure 2. Lactation curves of milk yield, fat, protein, and lactose contents.

4. Discussion

4.1. Local Available Ingredient Nutritive Values

The crude protein content for the majority of forages is less than 7%, with the exception of sorghum flour, sorghum silage, *T. dolonepfolius* hay, and *Piliostigma* sp. pod with 7.13%, 10.65%, 9.25%, and 7.68%, respectively. The poor nutritive content could be due to late harvesting and bad conservative conditions. It is known that climate plays an important role in the chemical composition of forages, especially high temperatures [16–18]. Similar findings were reported by [19]. From their study, the quality of crop residues decreases from harvesting time to animal feeding time, especially during the dry season [19].

This is why there is high NDF, ADF, and ADL content in the current forages. Forages gradually lose their nutritive value when the storage conditions are not good [19,20]. When forages lose leaves, the proportion of stems increases and ADL and NDF content is high [19,21]. Forage conservation determines its quality and the way farmers store the forage contributes to an increase in the lignin content and a decrease in forage digestibility. In those conditions, forages cannot meet the requirements of livestock, especially during the dry season [22]. This is why most farmers supplemented dairy cattle diets with soybean hay (8.27% CP; 25.46% CF) and sorghum silage (105% CP; 25.7% CF). The proportion for soybean hay, sorghum silage, and green forages was 18.18%, 42.42%, and 48.81%, respectively. Those data and results indicated that it is always relevant to supplement cattle diets by higher energy and nitrogen contents in ingredients.

4.2. Simulation Diets and Suggestions

There are diverse feed resources for domestic animal feeding with good nutritive value. Unfortunately, the bad conservation and use of those resources by farmers is the key negative effect on milk production. Therefore, 60% of concentrates are used in the feeding of dairy cows for lower milk yield. This is a significant energy waste also reported by [23], who reported that most dairy farmers typically fill the forage nutrient gap by increasing the proportion of concentrates in the diet. Those diets have higher energy content and lower fiber content and negatively affect dairy cow's productive and reproductive performances. There is an acidosis risk because of the decrease in rumen pH due to the supplement of concentrates in the diet. In this kind of feeding system, a farmer loses a lot of milk and also could lose his cow at any time. This is why an attempt is carried out by using Op-Ration in order to be able to suggest an optimal diet, including local feed ingredients, not well-used by dairy farmers in Burkina Faso. Our results clearly show that farmers are wasting forages for less milk per cow. Op-Ration is a good tool for making the optimum diet for dairy farmers by using their well-known and affordable ingredients. However, Op-Ration is not the only software to make dairy cattle diets. The French Research Center (INRA) also makes dairy cow diets using [15]. Previously, Ref. [24] used PRODLAIT to formulate a diet for dairy cows according to the lactation shape. Ref. [25], through LIVSIM, tried to predict cow milk yield by correlation with the body conditions score (BCS). In principle, there is not a big difference between software, but the types of ingredients available in the area could lead to bad or quality diets. When the data are well recorded in the software, the automatic calculation is conducted [26].

4.3. Raw Milk Yield and Chemical Composition Importance During Diet Calculation

In the current recording study, dairy cows were at different lactation stages and subjected to twice-daily milking. The feeding system was based on natural pastures which could have an effect on milk yield and quality. The lower milk yield from evening milking compared to morning milking could be explained by the shorter milking interval reported by [27,28]. Milk fat increases by 0.32 to 2.1% and protein content by 0.086% to 0.14% during evening milking compared to morning milking. Close previous results were reported by authors [29–33]. All those references clearly show that it is a well-documented aspect of raw milk for any dairy cows [34]. In Table 8, lactose content did not show any significant variation, which means that there is no disorder in the mammary gland function. However, lactose content was close to what has been previously reported by [32]. In general, the lactose content of different breeds of dairy cows is between 4 and 5% and is highly correlated to the production capacity of an individual cow. On the other hand, milk samples were run seven hours after milking and the fermentation process could have played a role in decreasing raw milk lactose content in the current study.

5. Conclusions

There are various feeding resources for milk production in Burkina Faso but dairy farmers have very low technical capacity. There is a big gap between the higher amount of

dry matter received by individual cows and the lower milk yield per day. Milk yield should be the outcome of the forage and concentrate amounts used in the diet. The results from Op-Ration confirm that it is possible to formulate a dairy cattle diet from locally available ingredients for higher yield per cow. This feeding process could be used in any region of Burkina Faso or elsewhere if the ingredients are well-known and the requirements of the animal are also determined (energy, nitrogen, and dry matter intake).

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Abbreviations

ADF	Acid detergent fiber
ADL	Acid detergent lignin
AIBP	Agro-industrial by-products
AOAC	Association of Official Analytical Chemists
ANOVA	Analysis of variance
BC	Gross Cellulose
BCS	Body conditions score
BNTD	Base Nationale Topographiques data
°C	Celcius degree
CF	Crude fiber
CP	Crude protein
CREAF	Recherches Environnementales, Agricoles et de Formation
DM	Dry matter
DT	Theoretical degradability
dr	Actual digestibility
E	Evening
EM	Metabolizable energy
ENEC II	Enquête nationale de l'effectif du cheptel tome II
ENEV	Net energy for maintenance and meat production
ENL	Net energy for lactation
FC	Fat content
F	Fat
g	Gram
kcal	Kilo calorie
Kl	Output of métabolisable energy in clear energy for the production of milk

Kg	Kilogram
Kmf	Output of métabolisable energy in clear energy for maintenance
L	Lactose
L	Liter
M	Morning
mL	Milliliter
MM	Mineral matter
N	Nitrogen
NDF	Neutral detergent fiber
PC	Protein content
TNM	Total Nitrogen Matter
OM	Organic matter
MAT	Total nitrogenous matter
MOD	Digestible organic matter
MOF	Fermentable organic matter
Pm	***Panicum maximum***
PDIA	Digestible protein in the small intestine from feed
PDIE	Digestible protein in the intestine from available energy

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