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Intra-annual variation in feed and milk composition in smallholder dairy farms in Kenya

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ABSTRACT

This longitudinal study explored intra-annual variation in feed availability and the chemical composition of milk and feed resources at smallholder dairy farms in Nakuru county, Kenya. Feed and milk samples were collected for a full year, every last week of the month, from 43 purposively selected farms. Feed and milk samples were analysed for nutritional composition using near infrared spectroscopy (NIRS) and Ekomilk milk analyser, respectively. The main basal feeds were indigenous grasses, Napier grass, maize and bean stover and maize silage, which farmers supplemented with purchased commercial concentrates and/or purchased or homemade total mixed rations (TMR). Commercial concentrates had the highest crude protein (CP) content (17.4 ± 3.9)% dry matter (DM), while maize stover had the lowest (8.7 ± 3.3% DM). All the feeds had low metabolisable energy (ME) that ranged from 7.0 ± 0.8 (MJ/kg DM) megajoules per kilogram of dry matter (MJ/kg DM) for maize stover to 8.9 ± 0.8 for dairy meal. Only grasses showed significant seasonal variation in CP and NDF ($P > 0.00$). Milk physicochemical composition was within the range stipulated by the Kenya Bureau of Standards (KEBS). Milk physicochemical composition showed negligible seasonal variations to significantly affect milk processing, which suggests that farmers can cope with feed scarcity. Nevertheless, seasonal feed availability is a persistent challenge in smallholder dairy farms. There is a need to ensure sufficient feed availability throughout the year in smallholder dairy farms through feed conservation, feeding management and ration preparation to enable consistent milk production and physicochemical composition.

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1. Introduction

Livestock production is one of the most important agricultural activities in Kenya and contributes substantially to agricultural Gross Domestic Product (GDP; Anyango et al., 2018; Gakige et al., 2020). Mixed crop-livestock smallholder farmers produce approximately 70% of the total milk marketed in Kenya (Anyango et al., 2018; Onyango et al., 2019). Smallholder dairy farming systems are diverse and include extensive grazing systems, semi-intensive semi-grazing systems and intensive zero-grazing systems (Migose et al., 2018). These dairy farming systems depend on grazed or cut native pastures and grasses, crop residues and agricultural by-products as feed resources (Onyango et al., 2019).

Feed scarcity is one of the major challenges affecting smallholder dairy production in Kenya (Njarui et al., 2021). Feed production in smallholder dairy farms is largely rain-fed, and rainfall patterns are highly variable and often unpredictable; feeds are abundant in the wet and early dry seasons, and scarce in the long dry season. Crop residues are only available immediately after harvesting (Anyango et al., 2018; Gakige et al., 2020; Mburu et al., 2018; Mwendia et al., 2017; Onyango et al., 2019). Feed availability is also influenced by agro-climatic conditions, that is, feeds are abundant in highlands and scarce in lowlands, arid and semi-arid areas (Onyango et al., 2019). In mixed crop-livestock production systems, feed production can be constrained by small land sizes that create a food-feed production dilemma, that is, farmers must decide whether to produce human foods or livestock feeds (Gakige et al., 2020). The land is, however, more readily available in rural areas compared to urban and peri-urban locations (Migose et al., 2018). Feed chemical composition is influenced by production, harvest and post-harvest practices, such as fertiliser application, cutting interval and stage of plant maturity (Anyango et al., 2018). Feed resources are usually of high quality in the wet season, that is high crude protein (CP) and a high metabolisable energy (ME) content, while in the long dry season feed resources usually are of low quality, that is, low CP and ME and high fibre and lignin content (Kashongwe et al., 2017; Mburu, 2015).

Both the feed chemical composition and intake levels determine milk yields and composition (Imaizumi et al., 2010). The NRC. Nutrient Requirements of Dairy Cattle (2001) recommends that feeds should have ME content of a least 10 megajoules/kilogram of dry matter (MJ/kg DM) and CP content of at least 15–19% DM to meet a dairy cow's daily feed requirements. Low feed availability leads to reduced feed intake and impacts milk yield, particularly when the cow's nutritional requirements are higher than the nutrient intake from feeds (Colmenero & Broderick, 2006; Imaizumi et al., 2010). Dietary fibre content can affect milk fat content (Schwendel et al., 2015). Although milk protein content is mainly influenced by cattle genetics, it can be improved slightly by increasing the dietary CP (Kashongwe et al., 2017; Schwendel et al., 2015). In Kenya, seasonal variation in feed resource availability and feed quality causes seasonal variation in dietary composition and, consequently, milk physicochemical composition (Kashongwe et al., 2017; Onyango et al., 2019). For example, poor quality feeds with high fibre content may lead to elevated milk fat content, although milk production levels may be low (Schwendel et al., 2015).

Seasonal feed availability and quality variations are known to affect milk production and physicochemical composition (Kashongwe et al., 2017; Schwendel et al., 2015). In Kenya, several cross-sectional studies have explored milk physicochemical composition (Kabui, 2012; Kabui et al., 2015; Mwendia et al., 2017; Ondieki et al., 2015) and seasonal feed availability and quality (Carter et al., 2015; Lukuyu et al., 2019; Mburu, 2015). There is, however, a lack of studies investigating feed and milk composition across a whole year in a smallholder dairy farm environment. The objective of this study was, therefore, to simultaneously investigate the intra-annual variation of feed and milk physicochemical composition in smallholder dairy farms in Nakuru county, Kenya. The results of this study will contribute to the literature on feed and milk composition. This literature is currently limited, particularly in the case of smallholder dairy systems in Kenya and countries with similar production systems. Understanding annual trends in milk composition in smallholder dairy systems can enable processors make decisions as regards which dairy products to produce.

2. Material and Methods

2.1. Study area

Nakuru county has a favourable agroecological environment for dairy production, a high density of smallholder dairy farmers, and a large population of dairy cattle (Migose et al., 2018; Van de Steeg et al., 2010). The county has two cropping seasons a year, reflecting its bimodal rainfall pattern: a long dry season (January, February and March), a long wet season (April, May and June), a short dry season (July, August and September), and a short wet season (October, November and December; Kinyanjui, 2019).

The study employed the farming system framework explained by Migose et al. (2018) and Nyokabi et al. (2021) to classify smallholder dairy production based on their intensification levels and market quality (access to markets for inputs and milk output). These farming systems include intensive urban and peri-urban dairy farming systems, semi-intensive mid-rural dairy farming systems and extensive, extremely rural dairy farming systems. In Nakuru county, intensive urban and peri-urban dairy farming systems encompassed farms in Nakuru town and Rongai, semi-intensive mid-rural dairy farming systems included farms in Njoro and Elburgon, while extensive, extremely rural dairy farming systems reflected farms in Molo and Keringet.

2.2. Smallholder dairy farms selection

Smallholder dairy farms were purposively selected across Nakuru county, including in Nakuru town, Rongai, Njoro, Egerton, Mwisho wa Lami, Elburgon, Molo and Kapsita. The criteria used to select smallholder dairy farms were: (i) milking cows in early lactation, (ii) a herd size of around five cows to ensure year-round milk supply, and (iii) farmers willing to participate in the study. The study started with 50 farms; however, 7 farmers dropped out and several farmers could not be reached for sample collection in some months due to logistical challenges, that is, inaccessible roads in the rainy season, selling of animals, farm relocation and security advisory during the election period. Consequently, the results of this study reflect data collected from the remaining 43 farms. We collected the data on farm characteristics, such as cattle breed, feeds grown, farm locations, at the beginning of the study. At the end of the study, we followed up this initial data collection to understand farmers' perception of feed availability during the year and how they coped in times of feed scarcity.

2.3. Data collection

2.3.1. Feed resources availability

Feed resource availability was assessed qualitatively through discussions with farmers. We assessed availability based on the quantities of feed available to the farmers to sufficiently feed the cows for a month without the need to source extra feed resources from outside the farm. Feeds were considered scarce when the amount available on the farm was not sufficient to feed cows over the month and the farmer had to actively look for additional feeds beyond the farm to sufficiently feed their animals. This entailed purchasing from external sources, such as traders, input and extension providers (commonly known as agrovets) or other farmers. The data was recorded monthly as notes and pictures including feed availability and scarcities and farmer coping strategies, by the first author.

2.3.2. Feed and milk sampling and analysis.

2.3.2.1 Feed sampling. Feed samples were collected during the last week of every month. On each farm, samples of 200–300 g were collected of each feed available in the feed trough for the cows. The feed samples included both dry and fresh feeds. Feed samples were chopped and sun-dried for a week before being stored in sealed plastic bags away from sunlight in a cold room for subsequent analysis. In total, 539 feed samples were collected during the study period. Feeds were categorised into local grasses, Napier grass (*Pennisetum purpureum*), maize silage (*Zea mays*), crop residues (stover), commercial concentrates (dairy meal) and home-made total mixed ration (TMR), that is, mainly purchased by-products of cereal milling, such as maize germ, maize bran, wheat bran, cotton-seed cake, mineral and vitamin additives mixed at home.

2.3.2.2 Feed laboratory analyses. Laboratory analyses of feed samples were undertaken at the animal nutrition laboratories of the International Livestock Research Institute (ILRI) in Addis Ababa, Ethiopia. Feed samples collected from the farms were oven-dried at 60°C for 24 hours to standardise moisture conditions and ground through a 2 mm sieve screen with a Wiley mill and analysed for crude protein (CP), metabolisable energy (ME), organic matter (OM), neutral detergent fibre (NDF), acid detergent fibre (ADF), and acid detergent lignin (ADL) using the near-infrared reflectance spectroscopy (NIRS) technique using FOSS Forage Analyser 5000® with WinISI software package®. NIRS is an indirect analytical method based on empirical models in which the concentration of a feed constituent is predicted from complex spectral data (Ayantunde et al., 2014). The NIRS calibrations and prediction equations used in this study were developed based on wet chemistry analysis of tropical feeds by the ILRI nutrition laboratories in Addis Ababa, Ethiopia.

2.3.2.3 Milk sampling. Milk samples were collected in the final week of each month over the one-year data collection period. In total, 607 milk samples were collected during the study period. On each farm, 100 ml of milk was sampled from the bulking container after morning milking in sterile bottles and stored in a cooler with ice packs. These samples were transported for analysis to the Regional Veterinary Laboratories (RVL) in Nakuru.

2.3.2.4 Milk laboratory analyses. Milk samples were homogenised and milk composition analyses were conducted using an Ekomilk milk analyser (Ekomilk milk analyser, Aeon Trading, Stara Zagora Bulgaria) for butterfat, solid not fats (SNF), protein, density and freezing point. Milk composition was compared to the Kenya Dairy Standards (KeBS): butterfat not less than 3.25%; protein not less than 3.5%; solid not fats not less than 8.50%; density 1.028–1.036 g/ml and freezing point −0.525 to 0.550 °C.

2.3.2.5 Milk and feed statistical analyses. Feed and milk data were tested for normality with the Shapiro–Wilk test. The mean and standard errors of feed and milk composition were calculated for the seasons. The data were subjected to a One-Way Analysis of Variance (ANOVA) to compare intra-annual variation in feed and milk chemical composition. Significant variations were declared at $p < 0.05$.

Two mixed models were used to test for seasonal and feed effects, and their interaction in determining feed and milk composition. The feed chemical composition model had CP, ME, OM, NDF, ADF and ADL as the dependent variables, while season and feed categories (feed were categorised into local grasses, Napier grass (*Pennisetum purpureum*), maize silage, crop residues (stover), commercial concentrates (dairy meal) and home-made total mixed ration (TMR)) were designated as independent variables, as shown in model 1:

$$Yijk = \mu + Si + Fk + eijk \qquad \text{Model 1}$$

Where: Yijk = dependent variable (general observation); μ = the overall mean; Si = effect of the ith season (i = long rainy, short dry, short rainy and late dry seasons); Fk = effect of kth species/feed type (grasses, Napier grass, maize silage, crop residues, dairy meal and TMR); eijk = error term.

The mixed model for the milk composition had butterfat, protein, solid-not-fats (SNF), density, freezing point, total solids, and fat: protein ratio as the dependent variables and the month and farming system (intensive urban, semi-intensive, and extensive rural dairy systems) and their interaction effects as the independent variables as shown in model 2. Dairy farming systems were chosen because they influence the feeding practices and breeds kept as explained by Migose et al. (2018).

$$Yijk = \mu + Si + Fk + eijk \qquad \text{Model 2}$$

Where: Yijk = dependent variable (general observation); μ = the overall mean; Si = effect of the ith season (i = long rainy, short dry, short rainy and late dry seasons); Fk = effect of *k*th farming system (k = intensive urban, semi-intensive, and extensive rural dairy systems); eijk = error term.

Statistical analyses were conducted using R statistical software version 4.2.1 (R Core Team, 2022) within RStudio (RStudio Team, 2022). The mixed models were done using nlme and LME4 statistical packages of R statistical software.

3. Results

3.1. Smallholder dairy farms characteristics

Table 1 summarises the characteristics of the smallholder dairy farms included in this study. The majority of the farmers kept Holstein–Friesian crosses and Ayrshire crosses due to their high milk production potential. Farms in urban and peri-urban areas had small land sizes and were intensive, zero-grazing systems. Farms in rural areas were either semi-intensive cut and carry or extensive semi-grazing systems (such as zero-grazing, tethering or free grazing or the fields with supplementation with concentrate feeds in the morning and evening during milking). Farmers in rural areas had more land, grew their feeds themselves, and were less dependent on purchased feeds than farms in urban areas.

3.2. Feed availability

The main feeds grown by the majority of the farmers were maize (*Zea mays*) and Napier grass (*Pennisetum purpureum*). Four of the sampled farmers grew Rhodes grass (Boma variety) (*Chloris gayana*) and native grasses. Farmers also grew other fodder and legume crops including lucerne (*Medicago sativa*), oats (*Avena sativa*), Bracharia grass (*Brachiaria spp.)*, cabbage and kales (Brassica *oleracea*), barley (*Hordeum vulgare*), sorghum (*Sorghum bicolour*), sweet potato vines (*Ipomoea batatas*), desmodium (*Desmodium spp*.) and vetch (*Vicia spp.)*. These fodder and legume crops were mixed with the basal feeds but accounted for a small amount of the total feeds supplied to cows.

Table 2 presents seasonal feed resources available in smallholder dairy farming systems compiled from the discussions with the remaining 43 participating farmers. Feed resources, especially the main basal feeds: Napier grass and natural pastures were abundant in the rainy season and early dry season but scarce in the dry season. Farmers described feed resources, available in the rainy season, as being of good quality. In the dry season, feed resources were scarce, and farmers perceived them as being of poor quality and mainly consisting of crop residues, hay, and dry native grasses. Crop residues and dry native grasses were especially important in the dry season in mixed-crop farming systems in rural areas.

Farmers provided the basal feeds (grasses, maize silage, stover and Napier grass) to their cows, supplementing the feeds with the dairy meal and with TMR (homemade concentrates). These concentrates were made of cereal milling by-products, such as maize germ and bran, wheat bran, cotton-seed cake, minerals and vitamin additives. Although dairy meal and TMR could be purchased throughout the year, the quantity fed to cattle was low. The majority of farmers fed an average of two kilograms of dairy meal or TMR to each cow during milking, in the morning and evening.

Farms in urban and peri-urban areas faced feed production challenges due to small land sizes, usually less than two acres. Some farmers produced fodder and forage on rented or owned land in rural areas and, additionally, fed their cows purchased feeds. In contrast, farmers in rural areas had relatively good access to land and labour, which allowed them to practice mixed farming. Farmers produced feed on their farms as planted strips of fodder, in the same fields where they grew food crops, and they also utilised crop residues from beans, maize, peas, potatoes, bananas, and chicken droppings and weeds. Farmers in rural areas relied less on purchased concentrates and vitamins than peri-urban farmers. Low milk prices in rural areas made it difficult to depend on expensive externally sourced inputs due to their high cost and low-profit margins received. They preferred maize germ, maize bran, and other cereal milling by-products due to their lower cost compared to dairy

Table 1. Characteristics of sampled smallholder dairy farms in Nakuru county (in percentage).

		UL (n = 14)	MRL (n = 17)	ERL (n = 19)	Average (n = 50)
Herd sizes	Small (less than 10 cows)	21.4	58.8	78.9	56.0
	Medium (11-30 cows)	7.1	17.6	15.8	14.0
	Large over 30 cattle	71.4	23.5	5.3	30.0
Breed	Holstein-Friesians and its crosses	35.7	52.9	63.2	52.0
	Ayrshire and its crosses	64.3	41.2	36.8	46.0
	Local breeds	0.0	5.9	0.0	2.0
Farm size	Small (less than 5 acres [2.02 Ha])	14.3	64.3	94.7	62.0
	Medium (50-10 acres [2.02-4.04 Ha])	21.4	17.6	5.3	14.0
	Large (over 10 acres [4.04 Ha])	64.3	17.6	0.0	24.0
Milk prices (Ksh)	Rainy season	40-50	30-35	26-30	-
	Dry season	50-70	35-45	30-40	-

UL-urban locations, MRL-mid rural locations and ERL-extreeme rural location
1 Kenyan Shilling (Ksh) = 0.0088 United States Dollar

meal. Cows were also supplemented with mineral salts, provided either in combination with feeds or as a mineral block.

In the dry season, farmers in all locations adopted long-term and short-term strategies to cope with feed shortages. Short-term strategies involved feeding reduced amounts of feed to animals to provide maintenance energy until the feed availability situation improved, although it led to decreased milk production and, hence, reduced income. Farmers purchased crop residues from neighbours who did not keep cattle or were willing to exchange crop residues for manure. Only a handful of farms employed long-term strategies to increase on-farm feed production and conservation. These farmers were particularly those with large herd sizes, capital resources and/or large land sizes to grow feed. The adoption of forage conservation technologies, such as hay and maize silage making was low, with only five of the participating farmers conserving feeds.

3.3. Chemical composition of common feed resources

The chemical composition of feed resources is presented in Table 3. Feed chemical composition varied across the different feed resources available in smallholder dairy farms as evidenced by the high standard deviation from the mean. Commercial dairy meal and TMR were the best quality feeds with regards to nutritional value as they had the highest CP and ME, and lowest NDF, ADF and ADL. Maize silage and maize stover had the lowest CP values and considerable high NDF and ADF. There were intra-annual seasonal variations for the feed resources in smallholder dairy farms; only grasses showed significant variation in the CP ($P < 0.00$) and NDF content ($P < 0.00$) across the seasons.

Table 2. Feed resources available for cattle in smallholder dairy farms in Nakuru county (discussions with 43 farmers).

	Long Rainy Season			Short Dry Season			Short Rainy Season			Long Dry Season		
Feed type	April	May	June	July	August	September	October	November	December	January	February	March
Natural pastures (local grasses)	√	√	√	√			√	√	√			
Napier grass	√	√	√	√			√	√				
Maize silage				√	√	√			√	√	√	√
Crop residues (maize and bean stover)				√	√	√	√	√	√	√		
Concentrates (dairy meal)	√	√	√	√	√	√	√	√	√	√	√	√
Total and partly mixed rations (TMR)	√	√	√	√	√	√	√	√	√	√	√	√

The results of the mixed model analysis showed that the variation in the feed chemical composition is significantly determined by feed type ($P < 0.00$) and not by season (Table 4). Additionally, there was no significant interaction between feed and season that influenced feed chemical composition.

3.4. Milk composition

Table 5 presents the results of milk physicochemical composition. Milk physicochemical composition meets the Kenyan dairy standards: butterfat not less than 3.25%; protein not less than 3.5%; solid not fats not less than 8.50%; density between 1.028 and 1.036 g/ml; and freezing point between −0.525 and −0.550 °C. Milk protein content was higher in the long-wet season compared to other seasons ($P < 0.02$).

Table 6 presents the results of the mixed model analysis, which further confirmed that intra-annual seasonal variations affect milk physicochemical composition. There is an interaction of season and farming system with butterfat and the fat-to-protein ratio ($P > 0.05$ and $p > 0.00$ respectively). This could be related to the availability and type of feeds in the farming systems during the different seasons of the year such as high NDF content in the long dry season.

4. Discussion

The objective of this study was to investigate the intra-annual variation of feed and milk composition in smallholder dairy farms in Nakuru county, Kenya. The results of this study reveal that the seasonal availability of feed resources is indeed a major challenge for smallholder dairy farmers. Chemical composition varied between the available feed types with dairy meal and TMR having better nutritional value than stover and grasses. Only grasses showed significant seasonal differences in chemical composition for CP and NDF content across the seasons. Concentrates such as dairy meal and TMR used for supplementary feeding had better nutritional value than the main basal feed such as grasses, Napier grass, maize silage and maize stover. Milk physiochemical composition showed negligible seasonal variations across the season.

4.1. Feed resources availability

The type of feed resources available in smallholder dairy farming systems in Nakuru county (Tables 3 and 5) is similar to what has been reported in other studies in Kenya, including Franzel et al. (2003), Njarui et al. (2011), Mutua et al. (2012), and Mburu (2015). Farmers in Kenya mainly depend on Napier grass as a main basal feed (Njarui et al., 2021). In zero-grazing systems, especially in urban and peri-urban areas, farmers rely on “cut and carry” zero-grazing systems, which is a common feeding strategy in Kenya (Lanyasunya et al., 2006).

Table 3. Feed chemical composition across the different seasons in smallholder dairy farms in Nakuru county (mean ± standard deviation).

	Season	LDS [a]	LWS [b]	SDS [c]	SWS [d]	Average	Pr(>F)
CP	Grasses	13.5 ± 5.9	13.6 ± 5.6	15.2 ± 5.2 [d]	11.2 ± 5.1	13.4 ± 5.5	**0.00** **
(%DM)	Napier grass	9.6 ± 5.7	15.0 ± 6.0	12.6 ± 5.7	12.1 ± 8.0	12.0 ± 6.4	0.37
	Maize silage	11.4 ± 4.9	11.7 ± 3.0	11.4 ± 1.5	11.3 ± 3.3	11.4 ± 3.3	0.99
	Maize stover	7.9 ± 2.4	7.1 ± 2.3	8.8 ± 4.6	10.3 ± 3.7	8.7 ± 3.3	0.15
	Dairy meal	15.9 ± 3.0	15.9 ± 5.0	19.2 ± 4.7	17.7 ± 3.5	17.4 ± 3.9	0.14
	TMR	13.4 ± 4.4	13.9 ± 4.8	14.5 ± 4.9	12.4 ± 4.7	13.4 ± 4.7	0.19
ME	Grasses	7.4 ± 0.8	7.2 ± 0.8	7.4 ± 0.8	7.0 ± 1.0	7.3 ± 0.9	0.15
(%DM)	Napier grass	6.7 ± 0.5	7.2 ± 0.4	7.1 ± 0.2	7.3 ± 0.7	7.0 ± 0.5	0.09
	Maize silage	7.3 ± 0.6	6.9 ± 0.7	6.7 ± 0.3	7.1 ± 0.7	7.0 ± 0.6	0.39
	Maize stover	6.8 ± 0.8	6.7 ± 0.4	7.3 ± 0.6	7.3 ± 0.8	7.0 ± 0.8	0.25
	Dairy meal	8.9 ± 0.8	8.1 ± 1.1	9.0 ± 0.6	9.1 ± 0.7	8.9 ± 0.8	0.11
	TMR	7.9 ± 1.0	7.5 ± 1.2	7.8 ± 1.0	7.7 ± 1.1	7.7 ± 1.1	0.47
OM	Grasses	83.3 ± 3.9	80.8 ± 3.3	83.1 ± 4.2	83.3 ± 5.0	82.9 ± 4.4	0.10
(%DM)	Napier grass	77.6 ± 5.5	79.9 ± 3.9	80.7 ± 1.3	78.9 ± 4.1	78.8 ± 4.5	0.70
	Maize silage e	88.2 ± 2.1	86.0 ± 4.7	83.2 ± 3.8	86.9 ± 2.5	86.4 ± 3.4	0.07
	Maize stover	88.5 ± 3.8	88.1 ± 4.6	88.0 ± 3.6	88.1 ± 3.0	88.3 ± 3.5	0.99
	Dairy meal	88.4 ± 6.1	86.5 ± 5.0	88.5 ± 10.8	89.8 ± 3.0	88.9 ± 6.2	0.78
	TMR	88.1 ± 4.4	86.1 ± 4.7	87.5 ± 4.7	86.9 ± 4.8	87.2 ± 4.7	0.27
NDF	Grasses	61.1 ± 6.8	61.6 ± 7.2	59.2 ± 7.9	64.8 ± 8.2 [c]	61.7 ± 8.0	**0.00** **
(%DM)	Napier grass	60.7 ± 4.5	61.0 ± 3.4	58.7 ± 3.2	60.7 ± 4.5	60.6 ± 4.0	0.91
	Maize silage	51.0 ± 9.3	56.0 ± 8.1	65.3 ± 9.8	55.7 ± 10.7	56.4 ± 10.5	0.14
	Maize stover	79.2 ± 8.3	82.2 ± 6.7	75.5 ± 8.6	79.1 ± 8.7	79.1 ± 8.2	0.57
	Dairy meal	41.4 ± 8.3	38.1 ± 4.5	40.4 ± 8.9	41.1 ± 6.5	40.8 ± 7.3	0.87
	TMR	59.2 ± 14.5	62.7 ± 16.1	58.1 ± 17.1	60.6 ± 13.7	60.1 ± 15.1	0.62
ADF	Grasses	30.8 ± 8.2	31.5 ± 6.6	31.2 ± 9.2	33.5 ± 9.2	31.9 ± 8.7	0.41
(%DM)	Napier grass	42.7 ± 5.5	38.3 ± 5.5	36.7 ± 6.8	36.4 ± 7.7	39.4 ± 6.4	0.17
	Maize silage	28.2 ± 5.3	31.8 ± 10.2	42.1 ± 7.9	34.1 ± 8.9	33.8 ± 8.9	0.05
	Maize stover	39.6 ± 10.7	40.3 ± 5.6	35.0 ± 8.3	36.0 ± 7.9	37.9 ± 8.9	0.53
	Dairy meal	18.5 ± 6.2	20.3 ± 1.1	17.8 ± 3.8	18.1 ± 6.2	18.3 ± 5.4	0.88
	TMR	27.5 ± 8.7	29.3 ± 10.7	29.1 ± 10.6	31.3 ± 12.2	29.5 ± 10.8	0.38
ADL	Grasses	5.5 ± 1.1	5.8 ± 0.9	5.7 ± 1.6	5.9 ± 1.5	5.8 ± 1.4	0.72
(%DM)	Napier grass	3.5 ± 2.2	2.7 ± 0.7	2.9 ± 0.9	3.8 ± 1.5	3.3 ± 1.6	0.63
	Maize silage	5.9 ± 1.1	7.4 ± 1.7	7.5 ± 1.3	6.8 ± 1.8	6.8 ± 1.5	0.26
	Maize stover	5.3 ± 2.6	4.8 ± 1.4	3.6 ± 1.8	4.2 ± 2.0	4.6 ± 2.2	0.33
	Dairy meal	5.1 ± 1.2	6.2 ± 0.8	5.3 ± 1.7	4.9 ± 1.3	5.1 ± 1.4	0.38
	TMR	5.2 ± 2.1	5.5 ± 2.1	5.4 ± 1.8	5.7 ± 2.5	5.4 ± 2.2	0.75

CP – crude protein, ME – metabolisable energy, NDF – neutral detergent fibre, OM – organic matter, ADF – acid detergent fibre, ADL – acid detergent lignin, TMR – total mixed rations, LDS – long dry season (January, February and March), LWS – long wet season (April, May, June), SDS – short dry season (July, August and September), SWS – short wet season (October, November and December). Significance: "***"P < 0.001, P< "**" 0.01, P< "*" 0.05

Our study results revealed that the seasonal availability of feed resources is a major challenge for smallholder dairy production systems in Nakuru county. Results of discussions with farmers further revealed that feed resources were scarce in the long dry season, which led to dependence on crop residues and purchased feeds (Table 2). Also, Kashongwe et al. (2017) reported that more than 60% of smallholder dairy farmers in Nakuru County face feed scarcity in the dry seasons. Migose et al. (2018) reported that feed availability in Nakuru county is also influenced by land availability with urban areas having more acute feed resources scarcity compared to rural areas. Although farmers

Table 4. Mixed model analysis results showing effects of feed type, season and feed type–season interaction in smallholder dairy farms in Nakuru county.

	Feed type Pr(>Chisq)	Season Pr(>Chisq)	Feed: Season Pr(>Chisq)
CP	0.00***	0.22	0.47
ME	0.00***	0.38	0.51
NDF	0.00***	0.74	0.81
OM	0.00***	0.33	0.53
ADF	0.00***	0.98	0.38
ADL	0.00***	0.86	0.63

CP – crude protein, ME – metabolisable energy, NDF – neutral detergent fibre, OM – organic matter, ADF – acid detergent fibre, ADL – acid detergent lignin. Significance: "***"P < 0.001, "**" P < 0.01, "*" P < 0.05

supplemented basal feeding with TMR and concentrate (Section 3.2), other studies in Kenya have been reported to use low quantities of dairy meal and TMR for supplementation of the poor quality basal feeds due to their high cost and low milk prices (Mburu, 2015; Onyango et al., 2019; Sakwa et al., 2021).

The findings of this study reveal limited feed conservation in smallholder farms in Nakuru county that exacerbates the lack of feed, especially in the dry season necessitating supplementary feeding with high-quality feeds (Section 3.2). Previous research has highlighted that smallholder dairy farmers in Kenya lack technical knowledge for forage conservation and silage making, which exacerbates the seasonal feed shortages and impacts the availability and quality of feed resources (Mburu, 2015; Mutua et al., 2012). Moreover, the smallholder farmer coping strategy of reducing the amounts of feed given to

Table 5. Milk physicochemical composition (arithmetic mean and standard deviation) across seasons in dairy farms in Nakuru county.

	LDS [a]	LWS [b]	SDS [c]	SWS [d]	Average	p-value
Butter fat	3.7 ± 0.9	3.5 ± 1.0	3.6 ± 0.8	3.5 ± 0.8	3.6 ± 0.9	0.103
Protein	3.5 ± 0.3	3.6 ± 0.3 [c]	3.5 ± 0.3	3.5 ± 0.3	3.5 ± 0.3	0.02 *
Solid not fats	9.2 ± 0.9	9.5 ± 0.7 [c,d]	9.2 ± 0.8	9.2 ± 0.9	9.2 ± 0.8	0.00**
Density	1.031 ± 0.004	1.032 ± 0.003 [a,c]	1.031 ± 0.004	1.031 ± 0.004	1.031 ± 0.004	0.02 *
Freezing point	−0.60 ± 0.07	−0.62 ± 0.05 [a,c]	−0.6 ± 0.0	−0.6 ± 0.05	−0.60 ± 0.06	0.01 **
Total solids	13.0 ± 1.4	13.0 ± 1.2	12.8 ± 1.2	12.7 ± 1.2	12.8 ± 1.2	0.11
Fat: protein ratio	1.2 ± 0.5	1.1 ± 0.4	1.2 ± 0.5	1.1 ± 0.4	1.1 ± 0.4	0.03*

Kenya dairy standards (KeBS) define butterfat must be not less than 3.25%, protein must be not less than 3.5%, solid not fats must not be less than 8.50%, density 1.028-1.036 g/ml, and the freezing point should range between −0.525- 0.550 °C. LDS-long dry season (January, February and March), LWS – long wet season (April, May, June), SDS – short dry season (July, August and September), SWS – short wet season (October, November and December). Significance: "***"P < 0.001, "**" P < 0.01, "*" P < 0.05

Table 6. Mixed model analysis showing effects of season, farming system, and season-farming system interaction on the milk physicochemical composition of milk samples from dairy farms in Nakuru county.

	Season Pr(>F)	Farming System Pr(>F)	Season: Farming System Pr(>F)
Butterfat (%)	0.09	0.90	0.01 **
Protein (%)	0.02*	0.34	0.28
Solid not fats (%)	0.00**	0.39	0.52
Density g/ml	0.01 *	0.51	0.24
Freezing point °C	0.01**	0.47	0.30
Total solids (%)	0.09	0.58	0.12
Fat: protein ratio	0.01 *	0.90	0.00 **

Farming systems included intensive urban farming systems, semi-intensive farming systems and extensive rural farming systems. Significance: "***"P < 0.001, "**" P < 0.01, "*" P < 0.0

cows in the dry season negatively affects the performance of dairy cattle (Section 3.2). Reduced feed availability negatively affects dairy cattle as it reduces the availability of crude protein (CP), rumen degradable protein (RDP) and ME needed for milk production and composition (Colmenero & Broderick, 2006; Goopy et al., 2018).

4.2. Feed chemical composition

There were differences in the chemical composition of feed resources in smallholder dairy farms (Table 3). The quality of the main basal feeds available in smallholder feeds is of inferior quality compared to TMR and commercial concentrates (Table 3). Moreover, only grass showed seasonal differences in CP and NDF (Tables 3 and 4). In Kenya, poor feed quality in smallholder dairy systems limits dry matter intake, digestibility and cows' performance (Carter et al., 2015; Onyango et al., 2019). The results of this study show that the energy content ranged between 7.0 and 8.9 MJ/Kg DM, which is similar to tropical pastures (Laswai et al., 2013; Löfqvist, 2016). ME content was below the NRC recommendation for lactating cattle of 10 MJ/kg DM. Additionally, all the basal feeds failed to meet the NRC recommendation of CP content of between 15% and 19% of DM to meet a dairy cow's energy requirements except for dairy meal. Generally, feeds with an NDF content of less than 45% are considered to be of high quality; those between 45-65% are of medium quality; and those over 65% are of low quality (Bogale et al., 2008; Mpairwe et al., 2002). Feeds with ADF below 30% are considered to be of high quality and those above 40% poor quality (Mpairwe et al., 2002).

Grasses CP content in this study was within the range reported by (Mburu et al., 2018) and Löfqvist (2016). Previous studies have reported quality deterioration in grasses after harvesting and recommended the need for training farmers on haymaking to maintain feed quality during storage (Akakpo et al., 2020; Kashongwe et al., 2017). Grass quality changes as it matures, that is, from green fodder to dry hay, which could explain the variation in chemical composition across the different seasons (Löfqvist, 2016).

The data on maize stover CP (Table 3) was similar to values reported by Mburu et al. (2018). Maize stover is harvested at the post-hard-grain stage and, as a result, most of the dry maize stover available to farmers was of low quality and needs to be treated to improve quality (Kashongwe et al., 2017; Mburu et al., 2018). The low CP of maize stover could be attributed to the stage of harvesting and methods of storage (Akakpo et al., 2020; Mburu, 2015). Mburu et al. (2018) have reported that feed conservation methods used by smallholder farmers expose maize stover to the vagaries of weather and leaf shattering, leading to considerable losses. Previous studies have reported that the chemical composition varies by plant part, that is, maize leaves have higher CP levels (83 g/ kg DM) compared to the stem (66 g/kg DM) and husks (48 g/kg DM; Methu et al., 2001). Maize stover quality can be maintained for longer if harvested with low water content (Methu et al., 2001). Additionally, the maize quality can be improved by soaking it in molasses or mixing it with other better quality feeds (Kashongwe et al., 2017).

Data on maize silage chemical composition (Table 3) was similar to SNV (2019). Maize silage is a good source of energy but has low CP content (Goopy & Gakige, 2016). Compared to Europe, silage ME in smallholder farms in Kenya is thought to be 10–15% below the ME content of the maize silage in Western Europe due to poor crop management and maize silage storage practices (SNV, 2019).

The ME, CP, NDF and ADF contents of Napier grass (Table 3) were within the range reported by previous studies (Mburu et al., 2018; Onyango et al., 2019; Orodho, 2006). There was no significant seasonal variation in Napier grass chemical composition (Tables 3 and 4), which contradicts previous studies that have reported seasonal variations in CP and NDF in Kenya (Orodho, 2006). The lack of seasonal variations could be due to farmers' crop cutting and crop management practices and possibly favourable climatic conditions during the research year (Onyango et al., 2019; Orodho, 2006).

Among the available feed resources, dairy meal and TMR had good chemical composition for dairy cattle (Table 3). The CP and ME values for both dairy meal and TMR were below the values reported in previous studies (Löfqvist, 2016; Moller, 2018). These findings confirm previous studies that have reported the low-quality dairy meals in the Kenyan market, including low ME content (Moller, 2018). Previous studies in Kenya and Uganda have expressed concern about the poor quality of and/or sub-standard commercial feeds sold on the market (Moller, 2018). These high-quality feeds are expensive and increase production costs on smallholder dairy farms (Imaizumi et al., 2010; Moller, 2018). An increase in CP beyond 17%, as observed in this study, does not necessarily increase milk production but can influence milk protein content (Imaizumi et al., 2010; Zanton, 2016).

4.3. Milk composition

Milk physicochemical composition (Table 5) was within the range reported in previous studies (Kabui, 2012; Kabui et al., 2015; Ondieki et al., 2015). Butterfat, protein and SNF content showed negligible intra-annual seasonal variations (Tables 5 and 6), which shows that farmers can cope with the variations in feed availability (Table 2). Although negligible, the intra-annual milk physicochemical composition variation could be linked to seasonal feed availability in smallholder dairy farms (Kashongwe et al., 2014). The interaction of season and farming system effect on butterfat and the fat-to-protein ratio (Table 6) could be due to farm management practices in the farming systems as has been suggested by Migose et al. (2018). Milk physicochemical composition can be influenced by seasonal feed availability and feeding practices, that is, supplementation (Schwendel et al., 2015).

The milk protein content is determined primarily by the cows' genetics but can be marginally improved through feeding (Schwendel et al., 2015). The results of this study are in agreement with Kashongwe et al. (2017), who reported low fibre feeds can depress milk fat production, particularly during the rainy season. Feeding strategies based on the use of feeds high in NDF, such as a Napier grass-based diet (i.e. a high proportion of forages compared to concentrates) lead to more acetate production, which is associated with high butterfat content in milk (Kashongwe et al., 2014; Laswai et al., 2013; Sakwa et al., 2021). Additionally, prevailing environmental conditions such as hot weather and high humidity in the dry seasons can affect cows' DM intake, which could result in changes in milk composition (Goopy et al., 2018; Schwendel et al., 2015).

4.4. Possible limitations of the research approach

This study was undertaken in Nakuru county, in the highlands of Kenya, which may not be indicative of feed resources abundance and composition in the lowlands. The accuracy of feed composition analyses depends on the sampling procedure and the parts of feed resources sampled (Mburu et al., 2018). Concentrates and TMR have to be thoroughly mixed for the collection of a representative sample, which can be difficult, particularly for home-mixed TMR. NIRS offers a quick, cheap and non-destructive approach for feed analysis and enables a more rapid analysis of a large number of samples than wet chemistry. NIRS accuracy depends on the calibration of the equipment using wet chemistry data. Currently, there are no extensive databases for feeds in Kenya and East Africa that constrains NIRS calibration (Akakpo et al., 2020; Ayantunde et al., 2014). As the results of wet chemistry become more available, NIRS calibration and equations used for feed chemical predictions will become more accurate in predicting feeds composition in Kenya and East Africa (Ayantunde et al., 2014; Laswai et al., 2013).

5. Conclusions and recommendations

This research contributes to the literature and data on feeds and milk composition in Kenya. The study demonstrated that the prevailing seasonal conditions affected the availability of feed, and feed chemical composition varied between these feeds. In the long dry season, regular feed resources are scarce, in short supply and of low quality, which requires farmers to use supplementary feed resources. The study suggests that, in Nakuru county, feed resources type and availability are more important for dairy production than the intra-annual variation in feed chemical composition. Intra-annual seasonal milk physicochemical composition variations were present, but they were negligible to significantly affect milk processing which suggests that farmers can cope with feeds scarcity in the dry season. The variation in chemical composition between the different feeds shows the imperative to improve feed quality through intercropping different fodder crops to increase feed diversity and diversify nutrient sources. Further, feed availability is a persistent challenge in smallholder dairy farms, and thus there is a need for local context- and season-specific solutions to improve cattle feeding strategies. We propose further research on feed composition across different ecological zones in Kenya involving a larger sample size to compare variations and add additional perspectives.

Statement of ethics

This work had ethical approval from the International Livestock Research Institute's (ILRI) Institutional Research Ethics Committee (ILRI IREC) (REF: ILRI-IREC2017-09). IREC is accredited in Kenya by the National Commission for Science, Technology and Innovation (NACOSTI).

Disclosure statement

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