

Effect of Dietary calcium soap on energy intake, milk production and growth performance of Red Sokoto goats and their suckled kids

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Abstract

The aim of this study was to conduct a pilot study on evaluating the performance of lactating Red Sokoto goats fed calcium soap produced in Nigeria. Twenty-four lactating Red Sokoto goats of average liveweight of 26.53 ± 1.47 kg were balanced for parity and stage of lactation and then randomly allocated to three dietary treatment groups in a completely randomized design (CRD) of eight does per treatment group. The treatments were: Treatment A (control ration without calcium soap), B (ration with 50 g of calcium soap), and C (ration with 100 g of calcium soap). Does were offered 600 g per head per day of concentrate as a supplement to *Digitaria smutsii* grass hay given at equal amount. Estimated quantities of calcium soap consumed from the ration daily were 0, 44 and 86 g per head for the control, 50 g and 100 g calcium soap treatments, respectively. Feed intake of the goats were measured daily for 26 days and the energy intake estimated. The goats were milked twice a week and the daily milk yield estimated. The initial, final and weekly liveweights of the goats along with those of their kids were measured. Pre-prandial and 4-hour postprandial blood metabolites were determined. The results indicates that the inclusion of calcium soap reduced the intake of the supplement while the intake of hay and total dry matter were increased ($P < 0.05$) at 100 g calcium soap inclusion level. Calcium soap significantly ($P < 0.05$) increased daily dietary energy intake per metabolic size at 50 g calcium soap inclusion level, but the dietary ME required for maintenance by the lactating goats was significantly ($P < 0.05$) higher at 100 g calcium soap inclusion level. Although the successive increase in milk yield was not significant ($P > 0.05$), daily milk yield of the goats increased with dietary level of calcium soap with 50 g inclusion level being the most efficient in eliciting milk production. The milk fat and protein percentages were not affected but the total solids were significantly ($P < 0.05$) higher in the milk of goats fed calcium soap. There were no significant differences ($P > 0.05$) in the body weight loss by the lactating goats, but the degree of weight loss increased with increase in milk yield and the level of calcium soap fed across the treatments. The average daily gain (ADG) of the kids ranged from 18 to 31 g, and were not different ($P > 0.05$) among treatments. The serum concentrations of glucose, urea and triglycerides were also not affected ($P > 0.05$) whereas those of cholesterol were affected ($P < 0.05$) among treatments. It is concluded that calcium soap can be fed up to 100 g/600 g of concentrate in the diet of lactating Red Sokoto goats to enhance higher total dry matter intake and a 9% superiority in milk production was observed over the control. For efficiency of milk production, feeding 50 g of calcium soap in 600 g of concentrate to the goats was apparently the best. Being a pilot study in Nigeria, there is a need to re-evaluate the procedure of producing the calcium soap, and to ensure the acquisition of quality calcium oxide for the production.

Keywords: Calcium soap, goats, milk yield, liveweight

Running title: Dietary calcium soap on goat milk yield



Effet du savon calcique alimentaire sur l'apport énergétique, la production laitière et la performance de croissance des chèvres Red Sokoto et de leurs chevreaux allaités

Résumé

L'objectif de cette étude était de réaliser une étude pilote évaluant la performance des chèvres Red Sokoto en lactation nourries avec du savon calcique produit au Nigeria. Vingt-quatre chèvres Red Sokoto en lactation, d'un poids vif moyen de $26,53 \pm 1,47$ kg, ont été réparties de manière équilibrée selon leur parité et leur stade de lactation, puis assignées aléatoirement à trois groupes de traitement alimentaire selon un

plan complètement randomisé (CRD) avec huit chèvres par groupe. Les traitements étaient : Traitement A (ration témoin sans savon calcique), B (ration avec 50 g de savon calcique) et C (ration avec 100 g de savon calcique). Les chèvres ont reçu 600 g par tête et par jour de concentré en complément au foin de Digitaria smutsii distribué en quantité égale. Les quantités estimées de savon calcique consommées quotidiennement étaient respectivement de 0, 44 et 86 g par tête pour les rations témoin, 50 g et 100 g de savon calcique. L'ingestion alimentaire des chèvres a été mesurée quotidiennement pendant 26 jours et l'apport énergétique estimé. Les chèvres ont été traitées deux fois par semaine et la production laitière quotidienne a été estimée. Les poids vifs initiaux, finaux et hebdomadaires des chèvres ainsi que ceux de leurs chevreaux ont été mesurés. Les métabolites sanguins pré-prandiaux et 4 heures post-prandiaux ont été déterminés. Les résultats indiquent que l'inclusion de savon calcique a réduit l'ingestion du concentré, tandis que l'ingestion de foin et la matière sèche totale ont augmenté ($P < 0,05$) avec l'inclusion de 100 g de savon calcique. Le savon calcique a significativement ($P < 0,05$) augmenté l'apport énergétique quotidien par taille métabolique à un niveau d'inclusion de 50 g, mais l'énergie métabolisable (ME) nécessaire à l'entretien des chèvres en lactation était significativement ($P < 0,05$) plus élevée à un niveau d'inclusion de 100 g. Bien que l'augmentation successive de la production laitière ne soit pas significative ($P > 0,05$), la production laitière quotidienne des chèvres a augmenté avec le niveau de savon calcique, le niveau de 50 g étant le plus efficace pour stimuler la production laitière. Les pourcentages de matière grasse et de protéines du lait n'ont pas été affectés, mais les matières sèches totales étaient significativement ($P < 0,05$) plus élevées dans le lait des chèvres nourries au savon calcique. Aucune différence significative ($P > 0,05$) n'a été observée dans la perte de poids des chèvres en lactation, mais le degré de perte de poids a augmenté avec l'augmentation de la production laitière et du niveau de savon calcique administré. Le gain moyen quotidien (GMQ) des chevreaux variait de 18 à 31 g et ne différait pas ($P > 0,05$) entre les traitements. Les concentrations sériques de glucose, urée et triglycérides n'ont pas été affectées ($P > 0,05$), contrairement à celles du cholestérol ($P < 0,05$). Il est conclu que le savon calcique peut être administré jusqu'à 100 g/600 g de concentré dans l'alimentation des chèvres Red Sokoto en lactation pour améliorer l'ingestion totale de matière sèche, avec une supériorité de 9 % dans la production laitière par rapport au témoin. Pour une production laitière optimale, l'administration de 50 g de savon calcique dans 600 g de concentré semble être la meilleure option. Étant une étude pilote au Nigeria, il est nécessaire de réévaluer la procédure de production du savon calcique et de s'assurer de l'acquisition d'oxyde de calcium de qualité pour sa fabrication.

Mots-clés : Savon calcique, chèvres, production laitière, poids vif

Introduction

The productivity of ruminants in the country is still sub-optimal (Otaru *et al.*, 2016) because 90% of the ruminant species are still managed under traditional system where little or no attention is paid to the quality of feeds consumed by the animals. The importance of adequate intake of true protein, energy and other essential nutrients for growth, reproduction and milk production in ruminants has been well documented (Adu and Brinckman, 1981; Preston and Leng, 1987; Aregheore *et al.*, 1992; Rabelo *et al.*, 2003; McGregor, 2018., Leduc *et al.*, 2021; Ayers, *et al.*, 2022). For an example, energy is very critical

for milk production by dairy animals (Morand-Fehr and Sauvant, 1978). In developed countries, therefore, calcium soap (calcium salt) developed from the saponification of calcium with palm oil fatty acids, is used as standard energy supplement for dairy animal feeding to enhance milk production. Inclusion of calcium soap in the diet has increased milk production in cows (Schauff and Clark, 1992) and goats (Teh *et al.*, 1994) in quadratic manner with the level of inclusion, but not in sheep (Casals *et al.*, 2006). Trials with inclusion of palm oil in the diets of lactating goats at the National Animal Production Research Institute (NAPRI), Shika, Nigeria showed 50%

increase in milk yield, enhanced postpartum weight gains and elongation of lactation length in Red Sokoto goats (Otaru *et al.*, 2020). The Performance could have been better than observed if the palm oil was included as calcium salt or calcium soap. The technology for producing calcium soap has not been tried in Nigeria to the best of our knowledge. Hence, calcium soap is not available for farmers' use in the country as an energy-rich supplement for dairy animals. Production of calcium soap in the country will be of immense value to dairy farmers because it reduces excessive use of soluble carbohydrate in the diet and the associated problems. The "goaty" off-flavour in goat milk is attributed to the presence of medium chain C₆, C₈, and C₁₀ fatty acids in the milk (Astrup *et al.*, 1985), and the consumption of calcium salt of long-chain fatty acids-palmitic and oleic acids was observed to reduce short to medium chain fatty acids in goat milk (Teh *et al.*, 1994). A pilot study was therefore embarked upon to domesticate the production of calcium soap in Nigeria and evaluate its effects on the performance of the indigenous goat breed, the Red Sokoto goat. It was hypothesized that there will be no difference in milk production in goats fed diets containing calcium soap at 50 g/600 g or 100 g/600 g concentrate and those fed diet without calcium soap.

Materials and methods

Laboratory production of calcium soap (calcium salt)

Palm oil was purchased from an open market in Samaru, Zaria, Nigeria. It was saponified with quicklime (calcium oxide) of 25 kg manufactured by Cales Pascual S. L. in Spain) obtained from a Chemical and Reagents Shop in Zaria. The calcium oxide was initially pulverized and sieved into fine powder. With the aid of requisite

apparatuses – Heater (hotplate, 50°C - 300°C), Cat No: 6/ML -037 Gallenkamp, England, weighing scale (maximum 2000 g, d: 0.1 g; e: 1 g) model HC-D, Golden-Melter, USA, stirrer, thermometer and stainless buckets and distilled water, the fine powder, was reacted with palm oil to produce the calcium soap or calcium salt from saponification reaction between the fatty acids of the palm oil and calcium of the calcium oxide. The calcium soap was prepared using fusion method (Perez, 2007) and the procedure outlined by Momoh (2014, Personal communication) was followed. Distilled water was added to calcium oxide powder, the mixture quickly stirred and poured into pre-melted palm oil in a stainless steel bucket earlier put on a hotplate. The resulting mixture was allowed to react as evidenced in the water of the mixture boiling because of the exothermic nature of the reaction. The mixture was then stirred until the soap was formed and the water became clear (or colourless). The soft and wet soap was then wrapped in old used newspaper to dry before being ground for inclusion in the diet. A total of 107 kg of the salt (calcium soap) was produced for the study. Upon drying, the calcium soap or calcium salt became solidified and. The dry moulds of the salt (calcium soap) weighing an average of 2.06 kg were pulverized into fine powder before being mixed with other dietary ingredients.

Diets and dietary composition

Three iso-nitrogenous diets (diets A, B and C) were formulated to contain 16% crude protein and each of the diet had maize grain, wheat offal, maize offal, cotton seed cake, bone meal and common salt. While diet A was the control without calcium soap, diets B and C contained 8.33% and 16.66% calcium soap, respectively (Table 1).

Table 1: Ingredients and Chemical composition of experimental diets

Ingredients, % (as fed)	Diet A	Diet B	Diet C
Maize	31.50	23.17	14.84
Maize offal	15.75	14.36	11.27
Wheat offal	15.75	14.36	11.27
Cotton seed cake	34.00	38.28	44.46
Calcium soap	0.00	8.33	16.66
Bone meal	2.00	1.00	1.00
Common salt	1.00	0.50	0.50
	100.00	100.00	100.00

Chemical Composition, % (DM basis)	Diet A	Diet B	Diet C	<i>Digitaria smutsii</i> hay
Dry matter	94.66	93.50	94.31	94.60
Crude protein	16.93	15.66	15.93	6.64
Ether extract	11.22	15.69	16.86	5.10
Crude fibre	14.84	9.82	10.64	32.34
Neutral detergent fibre	28.36	28.49	33.68	62.90
Acid detergent fibre	17.78	13.25	16.47	43.06
Nitrogen-free extract	43.49	43.75	41.11	42.59
Ash	8.18	8.58	9.77	7.93
Gross energy, GE (MJ/kg)	16.50	19.12	20.67	15.67
Metabolizable Energy, ME (MJ/kg DM)*	10.86	12.75	13.66	10.32
ME (MJ/kg DM)**	12.34	13.36	13.43	9.96

*Estimated from bomb calorimeter determined GE using Garret *et al.* (1959) equations.

**Estimated using MAFF (1975) equation.

Animals, experimental design and management

Twenty-four lactating Red Sokoto goats of average liveweight of 26.53 ± 1.47 comprising 9 does in 1st parity, 12 does in 2nd parity and 3 does in 3rd parity and with a distribution of 6 does in 4 – 5 weeks, 12 does in 3 weeks and 6 does in 2 weeks of lactation were balanced for parity and stage of lactation and allocated to the dietary treatment groups of A, B and C in a completely randomized design (CRD). Each treatment contained eight lactating does. The initial weights of the animals were measured at the commencement of the experiment and each housed in an individual feeding pen fitted with a feeder and a water container. The goats in treatment (A), the control, received ration containing no calcium soap (calcium salt), while those in treatment (B) and treatment (C) were offered rations containing calcium soap and to consume daily quantity of 50 g and 100 g (of calcium soap, respectively). The quantity of daily ration to feed to the goats to ensure consumption of 50 g (for diet B) and 100 g (for diet C) of calcium soap given the proportion of the soap in the two formulated diets (Table 1) was estimated to be 600 g/head To avoid loss of the calcium soap (which was limited in quantity) inside hammer mill and mixer, it was not compounded along with the other ingredients in diets B and C, but was added to the rations and mixed thoroughly at the point of feeding. Five hundred and fifty grammes (550 g) of ration B was taken and 50 g of calcium soap was added and mixed.

Similarly 500 g of ration C was taken and 100 g of calcium soap added and mixed. Equal amount (600 g) of *Digitaria simutsii* hay as basal diet was fed to each of the animals after the supplement was fed. Clean and fresh water was provided every day for the animals, *ad libitum*.

Milking of does

The study lasted for 40 days including an initial adjustment period of 14 days. After the adjustment period, milking of the goats was commenced and done twice a week (on Wednesdays and Saturdays just for 26 days or almost 4 weeks). On the eve of the day of milking, between 17.00 h and 18.00 h, the kids were removed for overnight separation from their dams and rejoined with their dams after milking the following morning at between 7.00 h – 8.00 h. The quantity of milk collected each of the days were multiplied by a factor of 2 to get milk yield for 24 h since milk secretion rates at milking intervals of 8, 12, 16 and 20 h are the same (Bencini *et al.*, 2003). The estimates for the two days of the week were added together and divided by 2 to get the average daily milk yield for each week. Milk samples were taken from randomly selected 5 does in each treatment for milk composition determination. 4% FCM (fat-corrected milk) was estimated using the equation of Gaines and Davidson (1923) as $4\% \text{ FCM} = 0.4 \text{ M} + 15 \text{ F}$, where M = Milk yield in kilogramme, gramme or pounds, and F = milk fat yield in kilogramme, gramme or pounds, as the case may be.

Liveweight measurements

The initial and final weights of the kids and their dams were measured in addition to taking weekly weights. The kids' final weights were taken when they were 2 months of age when the study was terminated as against the normal practice of weaning kids at three months (90 days) of age in the farm. The weight of the dams were estimated using Salter scale (model 235 6S) of 50 kg capacity with a 200 g-unit) to which a jute bag containing the animals was attached. For the kids, a Kitchen Scale (Hana Kitchen scale of 20 kg capacity with 50 g-unit) was used with a deep plastic container (able to hold the kids) to which the scale was adjusted or zeroed, to weigh the kids.

Blood metabolite determinations

Three days to the end of the trial, 15 animals were randomly selected with 5 animals from each treatment group to sample their blood for metabolites. Blood was collected pre-prandial and four (4) hours postprandial via jugular venipuncture and centrifuged using MSE centrifuge at 3000 rpm for 10 minutes to harvest the serum. We had the challenge of the samples not separating into serum but into gelatinous phase even at 6000 rpm until we used a micropipette to puncture and stir the gelatin and centrifuged again before the serum separated. The serum was decanted into labelled serum vials and kept in the freezer until analyzed.

Chemical analysis

The dried samples of the feeds (concentrates and grass hay) were ground through 1mm sieve and further dried at 105° C for 24 hours to determine the dry matter. The nitrogen in the milk and dried samples of the feeds was determined according to Kjeldahl procedure (AOAC, 1980), while the neutral detergent fibre (NDF) and acid detergent fibre (ADF) of feeds were determined according to the procedure of Goering and Van Soest (1970). The AOAC (1980) procedures were followed to determine the crude fibre (CF), ether extract (EE) and ash content of the feed samples. The samples were ashed by charring in a Muffle furnace at 500° C for about three hours or until a whitish ash remained. The nitrogen-free extract was estimated by subtracting values of crude protein, ether extract, crude fibre and ash from the dry matter value.

Milk fat was determined according to the method of Gerber (1960). The Gross energy (GE) contents of the diets was determined using oxygen bomb calorimeter (Model E2K manufactured in South Africa). The dietary metabolizable energy (ME) contents were estimated both from their Gross energy contents using Garret *et al.* (1959) equations of $GE = 76 \text{ Mcal DE} = 62 \text{ Mcal ME} = 35 \text{ Mcal NE}$, and MAFF (1975) equation of $ME \text{ (MJ/kg DM)} = 0.012CP + 0.031EE + 0.005CF + 0.014NFE$. For Garret *et al.* (1959) equations, GE, DE, ME and NE represent gross energy, digestible energy, metabolizable energy and net energy, respectively, while for MAFF (1975) equation, CP, EE, CF and NFE are crude protein, ether extract, crude fibre and nitrogen-free extract contents of the feeds, respectively, expressed on g/kg DM of the feeds. Because, the ME determination through the GE contents gave similar values to the control diet (maize-based concentrate) and the grass hay, the MAFF values which gave the expected trend with respect to the supplements and the basal diet, were used to estimate the energy consumption by the goats. The serum samples were analysed for glucose, urea, cholesterol and triglycerides. Glucose was determined by the glucose oxidase method as described by Trinder (1969); urea by the diacetyl monoxime method of Marsh *et al.* (1965); cholesterol by the method of Abel *et al.* (1952) and triglyceride by using lipase method of Tietz (1990).

Estimation of energy intake for maintenance and production

Dietary ME (MJ/day) used for maintenance (ME_m) was estimated using the maintenance energy requirement of 422.7 kJ/kgW^{0.75} derived by Nsahlai *et al.* (2004) for non-dairy goats or other goat biotypes. Dietary ME (MJ/day) used for lactation (ME_{l-d}) was estimated using the equation: $ME_{l-d} = (5.224 \text{ MJ/kg of 4\% fat-corrected milk}) \times ((1.4694 + (0.4025 \times \% \text{ fat in milk}))/3.079)$ by Nsahlai *et al.* (2004) where, ME_{l-d} is the dietary metabolizable energy (ME) requirements (MJ/day) for lactation, 5.224 MJ is the dietary metabolizable energy requirement per day to produce 1 kg of 4% fat-corrected milk. Since the actual or observed yields by the goats were not up to 1 kg of FCM, the ME_{l-d} was also estimated by taking the ratio of the actual

4% FCM yield to that of the extrapolated 4% FCM yield of 1 kg, and multiplied by the ME required daily for the production of 1 kg of 4% FCM.

Statistical analysis

Data on daily dry matter intake of feed and daily milk yield whose values were correlated because of repeated measures, were subjected to analysis of variance for repeated measures according to Littell *et al.* (1998) using PROC MIXED procedure of SAS (SAS 2002, version 9.0). For the PROC MIXED procedure, Kenward-Roger correction for degree of freedom was used because of heterogeneous variances and covariances, and standard errors which are linear combinations of variances which cannot be estimated by a single mean square (Kaps and Lamberson, 2009). The statistical model used is: $Y_{ijk} = \mu + t_j + b_i + p_k + tp_{jk} + e_{ijk}$, where, Y_{ijk} is the response of animal i in treatment j at time k , μ is the overall mean, t_j is a fixed effect of the j th treatment ($j = 1, 2, 3$), b_i is the random effect of the i th animal ($i = 1, 2, 3, \dots, 8$) nested within the j th treatment, p_k is the fixed effect of k th time ($k = 1, 2, 3, 4$), tp_{jk} is the interaction between the j th treatment and the k th time, e_{ijk} is the random error.

For each variable analysed under this model, animal as a subject nested within treatment was subjected to four covariance structures: Compound symmetry (CS), unstructured (UN), autoregressive order [AR(1)] and heterogeneous autoregressive [ARH (1)]. The covariance structure that yielded the smallest Akaike's Information Criterion (AIC) and met the convergence criteria was used. Autoregressive order (AR (1)) was used for grass dry matter intake; unstructured (UN) for daily concentrate dry matter intake, compound symmetry (CS) for total dry matter intake; heterogeneous autoregressive [ARH (1)] for daily milk yield. Variables such as total dry matter intake per metabolic weight, the final liveweight changes and daily weight gains of dams and kids, milk production efficiency and blood metabolites were analysed as CRD using ANOVA of the General Linear Model (GLM) procedures of the Statistical

Analysis Systems (SAS, 2002, version 9.0) according to the following statistical model: $Y_{ij} = \mu + t_j + e_{ij}$, where Y_{ij} is the response of animal i in treatment j ($i=1, 2, 3, \dots, 8$), μ is the overall mean, t_j is a fixed effect of the j th treatment ($j= 1, 2, 3$), e_{ij} is the random error. Initial liveweights of the kids at the beginning of the feeding trial were used as a covariate. The least squares means of all the variables were separated using CONTRAST statement of SAS (2002, Version 9.0) and differences between least squares means were declared significant at $P<0.05$. The daily milk energy yield plus energy retained or loss, all expressed per metabolic body size, was regressed against daily energy intake per metabolic body size, and the maintenance energy requirement (MEM) when energy retained or loss was zero, was estimated to be 849 kJ ME/kg $W^{0.75}$. Owing to the fact that this value was high compared to previous estimates, 401 kJ ME/kg $W^{0.75}$ (Aguilera *et al.*, 1990), 422.7 kJ ME/kg $W^{0.75}$ (Nsahlai *et al.*, 2004) and 739.9 kJ ME/kg $W^{0.75}$ (Akinsoyinu *et al.*, 1975) and was with low R^2 value of 0.0546, it was discarded, and the Nsahlai *et al.* (2004) value (422.7 kJ ME/kg $W^{0.75}$) for non-dairy goat biotypes was used to estimate maintenance energy requirement in MJ ME per day.

Results and discussion

The chemical composition of the diets and the hay are presented in Table 1. The analysed crude protein contents of the diets were fairly close to the calculated CP content of 16% for the formulated diets. The inclusion of calcium soap increased the gross energy and metabolizable energy contents of the diets.

Dry matter intake

The least squares means of feed intake, milk yield and composition are presented in Table 2.

Although the concentrate DMI were similar, it decreased across treatments as the level of calcium soap in the diet was increased. The taste or palatability problem of calcium soap or calcium salt normally depresses its intake by animals (Grummer *et al.*, 1990; Klusmeyer *et al.*, 1991; Schauff and Clark, 1992).

Table 2: Least squares means of daily feed intake, milk yield and milk composition of Red Sokoto goats fed diets containing different levels of palm oil calcium soap

Parameters	Diets			SEM	Level of significance		
	A	B	C		A vs B	A vs C	B vs C
Dry matter intake (g)							
Hay	336.38	328.50	447.46	30.27	NS	*	*
Concentrate	534.37	524.78	519.30	7.10	NS	NS	NS
Total Dry matter	870.75	853.29	966.76	31.81	NS	*	*
Total DMI (g/KgW ^{0.75})	72.72	78.10	77.01	2.91	NS	NS	NS
Milk Yield							
Daily milk yield (mL)	535.78	552.32	582.32	54.35	NS	NS	NS
4% FCM	481.99	484.38	465.67	61.60	NS	NS	NS
Efficiency of milk production (yield, mL/g Feed)	0.61	0.65	0.61	0.06	NS	NS	NS
Efficiency of milk production (yield, mL/kg Feed DM)	610.00	650.00	610.00	60.00	NS	NS	NS
Milk Composition (%)							
Total Solids	10.20	15.35	13.79	1.10	**	*	NS
Fat	3.25	3.19	2.59	0.59	NS	NS	NS
Protein	2.97	3.41	3.78	0.30	NS	NS	NS

* = P<0.05; ** = P<0.01; NS = Not significant (P>0.05). + = MJ values based on assumed yield of 1 kg 4% fat-corrected.

DMI = Dry matter intake; FCM = Fat-corrected milk

The intake values of the basal diet, hay, was affected by the treatment. The intake was highest in the goats which received 100 g calcium soap and was improved ($P < 0.05$) by 33 – 36% compared to the control group and those that received 50 g calcium soap. The goats fed 100 g calcium soap had lower gut fill with the lower consumption of the soap and thus compensated for the lower intake of the soap with higher consumption of the grass hay. This agrees with the same response by lactating Granadina goats fed basal diet of long alfalfa hay supplemented with concentrate containing different contents of protected fat rich in polyunsaturated fatty acids (PUFAs) (Sanz Sampelayo *et al.*, 2002). The total DMI was also increased by 11 – 13% ($P < 0.05$) by the treatment and followed the same pattern as the intake of the grass hay. This is at variance with the observation on cows by Schauff and Clark (1992) who recorded significant decrease in total DMI in treated groups and severe intake depression in the treatment which received the highest level (9%) calcium salt inclusion when compared to the control. Similar study with Alpine (Teh *et al.*, 1994) and Saanen (Souza *et*

al., 2014) goats indicated that inclusion of calcium salt in the diet did not affect total DMI.

The difference between the present study and those of Schauff and Clark (1992), Teh *et al.* (1994) and Souza *et al.* (2014) in terms of DMI could be attributed to the different modes of feeding the calcium soap. In their studies the calcium soap was fed in total mixed ration (TMR) where the concentrate and roughage were consumed together as mixed while in the present study it was fed in a concentrate supplement fed before the hay, the basal diet. The extent to which a component of diet fills the gut determines the limit of consumption of the other succeeding component of the diet when the components are fed in sequence. The expression of the total DMI on metabolic weight basis indicated that the treatment had no effect ($P > 0.05$) as the values were comparable.

Milk production and composition

The daily milk yield of the goats ranged from 536 to 582 mL for the goats in the control group and the 100 g calcium soap group, respectively. Although the daily milk yield was not

significantly ($P > 0.05$) affected by the treatment as was also reported on cows (Schauff and Clark, 1992), goats (Teh *et al.*, 1994) and ewes (Casals *et al.*, 2006), there was a trend of increase in milk yield across the treatments as the feeding level of calcium soap was increased. Dos Santos Neto *et al.* (2021) reported significant increased yields of milk, milk fat and 3.5 % fat-corrected milk when lactating dairy cows were fed diets containing calcium soap of palm fatty acids. The addition of calcium salt to the diet usually increased milk yield in comparison to the control diet, even if not statistically significant. The studies by Schauff and Clark (1992) and Teh *et al.* (1994) indicated low dietary level of 3% calcium salt for better milk yield performance, and beyond which milk yield would decrease below the yield of the control group. The milk yield in the present study is comparable to the mean value of 566 mL earlier recorded for the Red Sokoto goats in mid lactation stage (Otaru *et al.*, 2020). The ability of calcium soap to elicit high milk production had no marked effect because the goats were already in mid lactation when the study commenced and it coincided with when decline in milk yield had set in due to apoptosis and influence of hormones occasioning gradual partitioning of nutrients for milk production away from the mammary gland to the body tissues (Capuco *et al.*, 2003). Otaru *et al.* (2020) observed that early lactation milk yield is usually higher than the yield at each of the later stages, as it accounted for 42 % of the total lactation yield in Red Sokoto goats in line with normal lactation curve of dairy animals. The efficiency of milk production which is the amount of milk producible by consuming 1 kg of the diet is apparently similar among the treatments, but numerically, diet B or offering 50 g of calcium soap was the most efficient as consumption of 1 kg DM of the diet produced the most milk of 650 mL.

The milk total solids was significantly affected by the treatment where the does offered the calcium soap at 50 g per head per day showed 50% superiority ($P < 0.01$) in total solids content over

that of the control. Treatments with higher total solids may support higher cheese yield since cheese yield is proportional to the quantity of solid-not-fat, especially milk protein, which in this study increased with increased dietary calcium soap. The milk fat and protein percentages were similar ($P > 0.05$) among treatments but they showed opposing trends to the increase in dietary calcium soap level. The content of milk fat decreased and that of protein increased with increase in dietary calcium soap. It was expected that the addition of protected fat would decrease the protein percent of milk (Dunkley *et al.*, 1977) and increase fat percent of milk (Yang *et al.*, 1978), but it was not so in this study. The fact that milk protein increased could be due to increased energy in the form of carbohydrate or a precursor capable of increasing blood glucose but not energy increase due to dietary fat (Emery, 1978). Although rumen propionate was not determined in this study, the trend of increase in serum glucose and milk protein percent with increase in dietary levels of calcium soap may have been caused by alteration of acetate:propionate ratio in favour of propionate (Ngidi *et al.*, 1990), which enhanced the production of more serum glucose (Garcia-Roche *et al.*, 2021), which in turn spared gluconeogenic amino acids from being used and make them available for milk protein synthesis (Knowlton *et al.*, 1998; Lemosquet *et al.*, 2009). Increase in ruminal level of propionate can depress or lower milk fat percent (Palmquist and Conrad, 1978; Tackett *et al.*, 1996).

Daily energy intake for maintenance and lactation

Table 3 shows the daily energy intake for maintenance and lactation of the goats. Estimated amounts of the daily concentrate supplement (metabolizable energy) consumed across treatments (not shown in Table 3) were 6.59, 7.01 and 6.97 MJ for goats which received 0, 50 and 100 g calcium soap, respectively.

Table 3: Least squares means of daily energy intake for maintenance and lactation by Red Sokoto goats fed diets containing different levels of palm oil calcium soap

Parameters	Diets			SEM	Level of significance		
	A	B	C		A vs B	A vs C	B vs C
Energy intake							
Total Dry matter	870.75	853.29	966.76	31.81	NS	*	*
Total Energy intake (MJ ME/day)	9.94	10.28	11.43	0.32	NS	*	*
Energy intake (kJ ME/kgW ^{0.75} /day)	831.95	941.51	910.17	32.17	*	NS	NS
Dietary ME for maintenance, MEm (MJ/day)	5.07	4.62	5.37	0.19	NS	NS	*
Dietary ME for lactation (MJ ⁺ /day)	2.37	2.31	2.03	0.38	NS	NS	NS
Dietary ME for lactation (MJ ⁺⁺ /day)	4.71	4.67	4.30	0.24	NS	NS	NS
Total Dietary ME for maintenance and Production (MJ/day)	7.43	6.93	7.40	0.44	NS	NS	NS
Dietary ME Efficiency (ME for maintenance and production/ME intake)	0.75	0.67	0.65	0.04	NS	NS	NS

* = P<0.05; ** = P<0.01; NS = Not significant (P>0.05); + = MJ values for the actual or observed 4% fat-corrected milk of the goats; ++ = MJ values based on extrapolated (assumed) yield of 1 kg 4% fat-corrected milk.

Corresponding values for total metabolizable energy intake were 9.94, 10.28 and 11.43 MJ with goats fed 100 g calcium soap having significant (P<0.05) higher value than goats on either of the other two treatments (0 or 50 g calcium soap) with similar values (Table 3). When expressed on metabolic size basis, goats fed the control diet had the lowest energy intake of 831.95 KJ ME/KgW^{0.75} which was only significantly (P<0.05) different from their counterparts fed 50 g calcium soap with highest intake of 941.51 KJ ME/KgW^{0.75}. Dietary ME used for maintenance (MEm) was highest in goats which received 100 g calcium soap with an increment significant (P<0.05) only to goats which consumed 50 g calcium soap and was lower in value by 14%. Goats on 100 g calcium soap treatment required more energy for maintenance than those in other treatments because they produced the most milk. Apparently, the explanation made by Luo *et al.* (2004) that dairy breeds of goats which produced more milk than the nondescripts and meat types

had higher ME for maintenance because of greater mass of metabolically active organs such as the liver, intestines, heart and kidneys (Webster, 1981), would lend credence to the reason advanced in the present study for the goats fed 100 g calcium soap. The dietary ME used for lactation and the total dietary ME used for both maintenance and lactation were similar (P>0.05) across treatments. The estimated efficiency of use of dietary ME for both maintenance and production was also similar but showed a trend of decrease with increasing dietary levels of calcium soap.

Growth performance of does and kids

Table 4 shows the least squares means of liveweights of the goats and their kids. All the lactating goats lost body weight during the duration of the experiment and the differences in daily weight loss between the treatments were not significant (P>0.05). This is consistent with earlier report of body weight loss by cows fed diets containing varying levels of calcium salt

(Schauff and Clark, 1992) and also dairy ewes fed diets with or without calcium soap (Casals *et al.*, 1999).

Table 4: Least squares means of liveweight performance of Red Sokoto goats and their kids fed diets containing different levels of palm oil calcium soap

Parameters	Diets			SEM	Level of significance		
	A	B	C		A vs B	A vs C	B vs C
Dam liveweight (kg)							
Initial							
	27.55	27.10	26.88	0.30	NS	NS	NS
Final							
	27.32	26.48	26.05	0.60	NS	NS	NS
Weight change	-0.23	-0.62	-0.83	0.50	NS	NS	NS
Average daily gain (g)	-8.80	-23.82	-31.95	8.81	NS	NS	NS
Kid liveweight (kg)							
Initial							
	4.04	4.40	4.55	0.18	NS	NS	NS
Final							
	4.65	4.88	5.36	0.33	NS	NS	NS
Weight change	0.61	0.48	0.80	0.24	NS	NS	NS
Average daily gain (g)	23.49	18.32	30.83	9.17	NS	NS	NS

NS = Not significant ($P > 0.05$).

The severity of body weight loss increased as the level of inclusion of the calcium soap increased. It would appear the goats mobilized their body reserves for milk synthesis because the apparent trend of response of milk yield across treatments to increase in dietary level of calcium soap was diametrically opposed to that of body weight performance with the goats producing the highest quantity of milk losing the most body weight. The body weight response in the present study, however, disagrees with the earlier observation on Saanen goats which were fed diets containing varying levels of calcium soap for seven weeks and the goats fed calcium salt at lower levels gained body weight. The goats fed at higher level lost body weight and had the least value of milk yield in that the milk yield exhibited a linear decrease with increasing dietary level of calcium salt (Teh *et al.*, 1994).

The final weights and average daily gain of the kids at two months of birth when the study was terminated were not significantly ($P > 0.05$) affected by the treatment, even though, numerically, compared to the control, there was 31% improvement in ADG of the kids of the

goats which were fed diet containing 100 g calcium and produced the highest quantity of milk. The lack of significant effect of calcium soap treatment on the weight performance of the kids agrees with similar observation on the lambs of ewes fed protected fat supplements (Casals *et al.*, 1999; Appeddu *et al.*, 2004). It has been reported that dam milk yield accounted for 61% of variation in pre-weaning ADG of kids (Otaru *et al.*, 2020). Therefore, in the present study since the treatment did not markedly affect dam milk yield, the pre-weaning growth rate of the kids did not show marked response to the calcium soap treatment. Furthermore, the short duration of the study (of 40 days due to the limited quantity of calcium soap) did not allow the kids to be weaned on the experiment at the right time of 90 days of age.

Blood metabolite concentrations

Table 5 shows the least squares means of blood metabolite concentrations of the goats. The serum concentrations of glucose, urea and triglycerides pre- and post-prandial were not affected ($P > 0.05$) by the treatment and this is consistent with earlier reports on goats fed similar fat

supplements (Teh *et al.*, 1994; Titi, 2011) and hydrogenated tallow in the case of plasma urea (Brown-Crowder *et al.*, 2001).

Table 5: Least squares means of blood metabolites of Red Sokoto goats fed diets containing different levels of palm oil calcium soap

Parameters	Diets			SEM	Level of significance		
	A	B	C		A vs B	A vs C	B vs C
Blood metabolites							
Glucose (mmol/L)							
Before	2.68	2.80	2.76	0.14	NS	NS	NS
After	3.04	3.42	2.88	0.20	NS	NS	NS
Urea (mmol/L)							
Before	4.22	3.68	4.42	0.45	NS	NS	NS
After	3.90	4.10	3.58	0.46	NS	NS	NS
Cholesterol (mmol/L)							
Before	3.78	4.62	5.24	0.36	NS	*	NS
After	3.52	4.52	5.08	0.31	*	**	NS
Triglycerides (mmol/L)							
Before	0.62	0.64	0.66	0.04	NS	NS	NS
After	0.58	0.54	0.50	0.05	NS	NS	NS

* = $P < 0.05$; ** = $P < 0.01$; NS = Not significant ($P > 0.05$).

Although the means of the treatments were comparable, there was a numerical increase in serum glucose concentrations when dietary level of calcium soap was increased to 50 g/600 g concentrate, thus supporting similar trend by Palmquist and Moser (1981) when fat was fed to lactating cows in their first experiment but contradicts the results they obtained in their second experiment, and the observations by Seabrook *et al.* (2011) when lambs fed control diet had higher glucose concentrations than the lambs fed diets in which 11 % of the carbohydrate source (corn) was replaced by calcium salts of fatty acids. Serum triglyceride concentrations decreased with increase in the dietary levels of calcium soap, but the decreases were not significant ($P > 0.05$) across treatments. This is in contrast to the observation by Palmquist and Conrad (1978) where blended hydrolyzed fat included in the diet for dairy cows and calcium soap in the diet for sheep (Kuran, *et al.*, 1999) significantly increased serum triglyceride concentrations. The observed decrease in triglyceride level could explain decreasing milk fat percent across treatments since a positive relationship has been established between milk fat percent and blood levels of glycerides and non-esterified fatty acids (NEFA) (Van Soest, 1963; Steele *et al.*, 1971). The mobilization of the

body tissue fat (evidenced by body weight loss) for milk production was highest with the animal which produced the most milk. Mobilization of body tissue fat was expected to cause increased levels of plasma lipids, NEFA and blood ketones and milk fat percent (Van Soest, 1963), but it was not so in this study, and it is difficult to explain the opposing trends of cause and effect. The concentrations of serum cholesterol for both pre- and post- prandial periods were significantly affected ($P < 0.05$) by the treatment. There was a significant ($P < 0.05$) increase in concentrations across treatments with increase in the actual consumption of calcium soap which was estimated from the mean daily ration or concentrate consumed to be 0, 44 and 86 g per head per day, respectively for the control, 50 g and 100 g calcium soap treatments. This agrees with previous reports of increase in blood cholesterol concentration consequent upon increasing intake levels of protected fat (Souza *et al.*, 2014) or unprotected fat (Otaru *et al.*, 2011; Otaru *et al.*, 2020) but is at variance with those of Bernard *et al.* (2005) and Titi (2011). While glucose concentration increased postprandial, those of cholesterol and triglyceride decreased compared to pre-prandial concentrations in all the treatments. The urea concentration did not show

such definite pattern of variation or fluctuation between pre- and postprandial periods.

Conclusion

It is concluded that calcium soap can be fed up to 100 g in the diet of lactating Red Sokoto goats to enhance higher total dry matter intake and 9% superiority in milk production over the control. For efficiency of milk production, feeding 50 g calcium soap/600 g of concentrate to the goats was apparently the best. Being a pilot study in Nigeria, there is a need to re-evaluate the procedure of producing the calcium soap, and to ensure the acquisition of quality calcium oxide for the production.

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