Recent research of feeding practices and the nutrition of lactating dairy goats*

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ABSTRACT

Dairy goats can mobilize considerable body fat for support of milk production, but this can necessitate a high nutritional plane later for replenishment. Tissue mobilization during gestation should be controlled so as not to impair lactational performance. Dairy goats can markedly vary feeding behaviour in response to factors such as restricted periods of access; however, further studies are needed to address the efficiency of production. With some tolerance of goats to plant secondary metabolites and voluntary consumption of a wide array of materials, regionally available byproducts and other nonconventional feedstuffs can be used to minimize production costs. Dairy goats are resilient to moderately harsh environmental conditions, but more extreme ones should be addressed with anticipated future climate change. Some differences in the effects of dietary inclusion of fats and oils between dairy goats and cattle may relate to ruminal microbial conditions as well as the susceptibility of mammary gland enzymes to bioactive conjugated linoleic acid isomers. Much research is being conducted to improve the fatty acid composition of fat in goat milk in regard to effects on human health through the use of fats and oils as well as plant secondary metabolites, and effects on antioxidant status are increasingly being considered as well.

1. Introduction

In 2016 a similar review of research conducted primarily in the preceding few years concerning feeding practices and the nutrition of lactating goats was presented at the 3rd Asian-Australasian Dairy Goat Conference and subsequently published (Goetsch 2016). The article could be considered somewhat analogous to ones in proceedings of Pfizer Annual Research Conferences held many years ago. Those articles entailed very brief overviews of all available journal articles published in the last year on specific areas of nutrition authored by different researchers each year. Though in many cases only one or a few sentences were used to highlight an article, many researchers extensively used these proceedings to easily and quickly identify publications of interest.

In the previous review on lactating goats, a search with ScienceDirect was performed with key words such as of dairy, goat, feeding, and nutrition, again with an emphasis on most recent articles. This was conducted for the current review as well, but for broader coverage of the available literature, there were searches performed of many other journals, with focus on the last few years and care taken to not address articles discussed in the previous review. Moreover, most publications overviewed were conducted with dairy goat breeds selected for milk production or crossbreds thereof when lactating.

As alluded to above, the objective of this review is to provide an overview of research of feeding practices and nutrition of lactating dairy goat breeds recently conducted. Though there is not an intent to critique or criticize publications, some comments are included pertaining to experimental conditions, procedures, findings, and(or) interpretation when felt warranted for most appropriate usage.

2. Production system

In many production systems there is appreciable variation in the nature of the diet throughout the year as the availability of different feedstuffs and grazed forage and browse plant species change. The study of Eknæs et al. (2017) provides an example of this, with indoor feeding of multiparous Norwegian dairy goats from day 1–120 and day 201–230 of lactation and mountain grazing between the indoor periods. Based on computer tomography, considerable fat was mobilized in the first 2 months of lactation, with visceral fat contributing more and mobilized at twice the rate compared with the fat of the carcass. Mobilization also was relatively high during mountain grazing, although there were similar contributions of the two fat depots. Hence, assuming body condition score (BCS) to be influenced to a greater extent by the fat of the carcass than viscera, it may be more reflective of capacity for tissue mobilization to support milk production in mid-lactation than earlier. In the first 200 days-in-milk (DIM), 72% of body fat was mobilized. Milk favour was not reported, but Eknæs et al. (2006) indicated that such levels of mobilization can result in high levels of free fatty acids (FA). The last month of indoor feeding facilitated increases in the mass of visceral and carcass fat depots of similar magnitude, but still with substantial need for additional tissue replenishment in the subsequent dry period to achieve similar condition and body weight (BW) for lactation 1 yr after
the start of this experiment. In fact, average daily gain (ADG) necessary from day 231 to the next lactation, with a period of 135 days assumed, would be quite high. Based on the 4.4 kg difference in mass of the sum of the two fat depots between 10 DIM and DIM of both 120 and 230, if a fat concentration of accreted tissue of 22.35% is assumed (Ngwa et al. 2009; mean of 25.2 and 19.5%), ADG of 146 g would be necessary. Furthermore, with the potential mobilization of tissue in late gestation as noted by Castagnino et al. (2015), even higher ADG could be required. Hence, changes in management practices during lactation to lessen mobilization would seem worthy of consideration. Based on these findings, it would not appear that accretion of fat in the different depots occurs in the same sequence as mobilization. There was a lack of agreement between change in BW, BCS, body mass index (BMI; BW in relation to height × length), and mass of fat depots, which may in part reflect appreciable shifts in the mass of gastrointestinal tissue and digesta and body water. Conceptually, BMI should more closely coincide with BW change compared with the more subjective measure of BCS. Perhaps the inclusion of a measure of circumference such as heart girth, presumably influenced by visceral fat mass, would improve relationships with BMI.

As noted in the study of Eknæs et al. (2017), both diet composition and the quantity of can fluctuate throughout the year. In this regard, Palma et al. (2017) conducted an experiment addressing seasonal weight loss with drought in areas such as the Canary Islands. The study began at approximately 3 months in lactation and was 23 days in length. The control dietary treatment entailed offering a typical diet for normal milk production and without BW loss, and the restricted treatment consisted of wheat straw consumed ad libitum. Two breeds of goats of the area were used, Majorera and Palmera, the former larger and thought less susceptible to seasonal weight loss than the latter. The ADG was 117, 48, −283, and −226 g for Majorera-control, Palmera-control, Majorera-restricted, and Palmera-restricted, respectively, with similar BW loss for both breeds as a percentage of initial BW (i.e. 13%). The restricted treatment decreased the level of C18:0 (palmitic acid) and increased that of C18:2 (linoleic acid) in total milk FA, although differences were only significant for Palmera with tendencies for Majorera. Decreased nutrient absorption with the restricted treatment presumably minimized de novo FA synthesis in the mammary gland for a greater contribution of FA from mobilized adipose tissue. This is similar to conditions in early lactation when nutrient and energy intake are less than needed to support milk production, resulting in limited levels of short and medium chain FA in milk and elevated concentrations of long chain FA, primarily C18:0 (stearic acid) and C18:1 (oleic acid), arising from mobilized tissue (Eknæs and Skeie 2006).

Panzuti et al. (2018) conducted a study addressing potential for adverse effects of high nutritional planes for Alpine doelings during growing on subsequent milk yield as has been observed in dairy cattle. Doelings were weaned at 40 or 60 days of age and offered concentrate ad libitum until 200 days when breeding began or restricted from day 130 to 200. As expected there were some small differences among treatments in BW and growth rate, but pregnancy rate, litter size, and milk yield and composition during the first lactation were not influenced. Thus, similar to flexibility shown in feeding behavior noted later, with modest treatment differences such as these, dairy goats have considerable capacity for compensatory growth. However, the authors encouraged future research during gestation when potential for deleterious effects of high nutritional planes on first lactation milk yield might be greater.

3. Tissue Mobilization

In some instances with dairy cattle highly selected for production, it is of interest to restrict milk fat yield in early lactation to improve energy balance. One means of achieving this is to increase the quantity of bioactive conjugated linoleic acid (CLA) isomers, primarily trans-10, cis-12, reaching the mammary gland. Because ruminal biohydrogenation is considerable, albeit influenced by many factors including dietary concentrate level, ruminal pH, tannins, and level and type of fat sources, means of protecting FA sources continue to be studied. An example is the study of Schmidely et al. (2017) in which multiparous Saanen or Alpine goats at 65 DIM were fed diets without or with commercial products of Ca salts of palm oil or lipid-encapsulated CLA isomers. The products provided 33–43% of total FA intake. Ruminal biohydrogenation of C18:1, C18:2, and C18:3 (linolenic acid) was 61%, 67%, and 53%, respectively, and not different among treatments. Less extensive biohydrogenation than for dairy cattle was postulated to be related to higher feed intake relative to BW and, thus, shorter ruminal digesta residence time.

As alluded to above, the transition period just before birth and in early lactation has been an intense area of research with dairy cattle highly selected for milk yield in regards to metabolic disorders associated with excessive tissue mobilization. This may be an important time for high-producing dairy goats as well. Therefore, Invernizzi et al. (2016) conducted a study with Alpine goats 28 months of age fed diets without added fat or with a rumen-inert fish oil or calcium stearate before kidding and through 21 DIM. Although, it is unclear when treatments were first imposed before variables were assessed at 7 days before kidding. Fish oil and stearate diets both decreased energy balance at 7 DIM (1.42, −3.81, and −4.69 MJ/day) but tended to increase balance at 21 DIM (−0.67, 3.72, and 3.43 MJ/day for control, fish oil, and stearate, respectively), with much greater differences among days than for the control diet. Although neither dry matter (DM) intake nor fat-corrected milk yield differed among treatments, other measures of hepatic and subcutaneous fat conditions suggested that fish oil reduced and delayed fat mobilization that could improve liver function during the transition phase. Without impact on milk composition, responsible factors are unclear. There would seem potential for mobilization of lipid from another depot such as the viscera as well as of proteinaceous tissue, the former but not the latter found quite important by Eknæs et al. (2017). Perhaps this contributed to negative energy balance with supplemental fish oil at 7 DIM and delayed subcutaneous lipid mobilization.

Tissue mobilization in the transition phase and while lactating can be influenced by conditions during gestation. Castagnino et al. (2015) addressed influences of litter sizes of 1 and
2 during gestation of Saanen and Oberhasli goats. Feed intake with a litter size of 1 was consistent throughout gestation, whereas intake by does with two foetuses decreased at an increasing rate in the last two-thirds of gestation. This appeared due to differences in weight of the foetus and associated tissues and fluids that decreased ruminal digesta capacity, and also hormonal conditions (oestrogen level and estrogen:progesterone ratio) were suggested to be involved. However, mobilization of tissue in late gestation did not differ between single and twin pregnancies. It was postulated that in some manner (s) digestibility was greater and/or the maintenance energy requirement for maternal tissues not directly involved in pregnancy was less for the litter size of 2 vs. 1. The former may relate to lower digesta passage rate for goats with a litter size of 2 assuming that reduced digesta capacity was not fully compensatory for lower feed intake. The latter difference might have resulted from the decreased mass of the gastrointestinal tract and, therefore, less energy used by this very metabolically active tissue for its service functions (Goetsch 1998). Change in maternal BW was similar between litter sizes. Over one-half of the increase in maternal BW occurred by day 80, with less change thereafter as expected and eventually steady values in the last one-third of gestation. This is despite appreciable mobilization, particularly of fat, suggesting substantial changes in mass of other tissues such as the gastrointestinal tract and in tissue water content, as noted earlier during lactation in the study of Eknæs et al. (2017). Protein accretion in maternal tissues occurred in the first 80 days of pregnancy. Nearly all protein mobilized thereafter was accreted in pregnancy tissues, whereas most energy from fat was used for doe maintenance, in particular in the last one-third of gestation. Although the results are interesting, intake of DM seems low, approximately 2.3% BW for does with a single kid litter, given that the diet was 55% concentrate. Furthermore, the dietary CP level of 11.6% could have been limiting in late gestation depending on feed intake, particularly for the litter size of 2. Perhaps some of these factors may account for findings such as similar intake between litter sizes that are not in accordance with intake of a 50% concentrate diet by meat goat does in mid- and late gestation that ranked litter size 3 > 2 > 1 (Tovar-Luna et al. 2007).

4. Feeding behaviour

The feeding behaviour of goats is often described as being flexible. Charpentier and Delagarde (2018) addressed this attribute in two sequential 3-wk experiments with Alpine goats in early to mid-lactation grazing grass-legume pastures. One experiment had treatments of 4, 6, and 8 h of pasture access and the other pasture forage allowance of 1.6, 2.3, and 3.0 kg DM per animal. Milk yield was slightly limited by the 4-h/day access and 1.6 kg DM allowance treatments. Time spent grazing was 3.9, 5.6, and 5.9 h for access treatments of 4, 6, and 8 h, respectively. Though intake of pasture forage DM was not estimated, by applying NRC (2007) energy requirements and use of organic matter (OM) digestibility of forage apparently selected as total digestible nutrient (TDN) concentration and no requirement adjustment for grazing activity with the Langston Interactive Nutrient Requirement Calculation system (LINC; http://www.luresext.edu/?q=Nutrient-Calculators), rate of forage intake was 4.3, 3.5, and 3.3 g/min for 4, 6, and 8 h of access, respectively. With 13 h of pasture access in the second experiment, time spent grazing was 8.2, 9.1, and 8.6 h for the low, moderate, and high allowance treatments, respectively. A lower amount of feed offered, other than pasture forage, in the second than the first experiment (1.13–1.15 vs. 2.02–2.12% BW) probably contributed to the relatively long grazing times. Relatedly, with the same methods noted above, the rate of forage DM intake was less than in the previous experiment, at 2.5, 2.6, and 2.9 g/min for the low, moderate, and high treatments, respectively. With the probable influence of grazing time on energy use for activity (Sahlu et al. 2004), it would be interesting to have determined total forage intake and potential treatment differences in efficiency of energy utilization in milk production. For example, even though milk yield was lowest for the shortest pasture access length in experiment 1, with the lowest grazing time perhaps efficiency of production was enhanced by a lower grazing activity energy cost. This is supported by some findings of Keli et al. (2017) with lactating Alpine goats subjected to a continuous access treatment compared with ones in which access was limited. Heat energy was greatest among treatments for the control treatment in nearly all hours of the day, perhaps because of the greatest time spent grazing and walking, despite the lowest distance travelled. Moreover, milk energy as a percentage of metabolizable energy (ME) intake was greatest for the treatment with pasture access between morning and afternoon milkings than for access continuously or for periods varying from day to day depending on leaf surface moisture level.

Possibly because grazed forage constituted a relatively low proportion of the diet (i.e. 34.8–48.8%) in the study of Keli et al. (2017), time spent grazing of 5.9–7.4 h was less than in the second experiment of Charpentier and Delagarde (2018) and the rate of DM intake was only 1.5–2.0 g/min. Results such as these suggest that if given free or relatively long access, lactating dairy goats spend more time eating than necessary. The same appears true for goats in confinement. For example, Silva et al. (2018) allowed Alpine goats in early to mid-lactation access to feed throughout the day (control) or for 2, 4, 8, or 16 h at different times. Heat energy and ADG were greater for continuous than for limited feeder access, which was accompanied by a tendency (P = .057) for lowest milk energy as a percentage of ME intake. It was postulated that the temporal pattern of nutrient availability may be relatively more important to peripheral tissue accretion than milk synthesis.

Feeding behaviour in confinement is receiving increasing attention, examples being the aforementioned study of Silva et al. (2018) and those of Keli et al. (2017) and Neave et al. (2018). For the latter study, DM intake by 13-month-old Saanen doelings in groups of three was greater with a feeder located above the head with access gained by use of a step compared with feeders on the floor and at head height. With similar time spent eating among feeder heights, the rate of intake tended to be greatest for the elevated feeders and feeder visits were lowest for the floor feeding. Displacements were greatest for the elevated height, which was suggested
to have been due to the greater preference for this feeder rather than greater vulnerability because of the position of legs. Future research such as these studies should be conducted with lactating goats and determination of level and efficiency of production as potentially affected by differences in energy use for activity. In this regard, a conclusion from the study of Keil et al. (2017) with lactating dairy goats was that the feed table or trough be at least 10 cm above the standing area, although feed intake and production were not reported.

5. Environmental stress conditions

5.1. Water

The quality of water available for drinking can influence level and efficiency of production, and an important characteristic of drinking water is the concentration of total dissolved or soluble salts (TDS), often termed as the level of salinity. Drinking water with TDS above 1000 ppm (i.e. mg/kg or litre) is termed ‘saline’, and brackish infers TDS between 1000 and 10,000 mg/kg. Ruminant livestock frequently consumes water moderate to high in TDS. Brackish and saline groundwater sources are widespread, including countries like Egypt (Assad and El-Sherif 2002), Australia (McGregor 2004), India (Sharma et al. 2017), Tunisia (Yousfi et al. 2016), Brazil (Castro et al. 2017), Asia, the eastern Mediterranean, Africa (Masters et al. 2005), and most of the central USA (Androwski et al. 2011; USGS 2013). There are a number of factors suggesting an increased reliance of ruminant livestock on drinking water relatively high in TDS in the future, along with higher TDS in saline water already being consumed. Particularly in low rainfall areas with limited surface water, groundwater can be heavily used, causing increased TDS in soil and groundwater (Yousfi et al. 2016). In many parts of the USA, surface water is completely allocated and rates of groundwater withdrawal are greater than those of recharge, resulting in decreased groundwater supplies, lower stream and lake levels, and(or) land subsidence, with an increased reliance on water high in TDS (Masters et al. 2005; El-Shaer 2010). Climate change may exacerbate these conditions, with decreasing and less consistent precipitation in some regions and increased evaporation.

Water salinity is frequently studied through the addition of NaCl to fresh water. In this regard, Paiva et al. (2017) conducted a study with multiparous crossbred goats of unspecified breeds in Brazil. Based on study initiation at 30 DIM, a trial length of 65 days, average milk yield of less than 2 kg/day, and initial BW of 38 kg, presumably the level of a breed highly selected for milk production was not more than 50%. Sodium chloride was added to fresh water (640 mg/l TDS) for TDS levels of 3,188, 5,740, and 8326 mg/l. Water intake increased linearly with increasing TDS concentration as often occurs with levels such as these but there were no effects of water TDS on feed intake, digestion, or milk yield or composition. However, it is unclear if findings would be similar with high-producing dairy goat breeds or natural sources of saline water high in other minerals. Very little research with small ruminants has been with actual natural sources of underground saline drinking water, exceptions being studies of Tsukahara et al. (2016) with meat goats and Yirga et al. (2018) with meat goats and hair sheep. The latter experiment suggested potential for different effects of TDS level altered by the level of a brackish water source and NaCl additions.

5.2. Heat

Dairy goats in many production settings are exposed to various stress factors throughout the year, inclusive of high temperature and(or) humidity. Decreases in milk yield with heat stress generally result from decreased feed intake, increased energy expenditure for heat dissipation, and changes in other physiological conditions. El-Tarabany et al. (2017) studied effects of heat stress in a 6-month experiment starting in early lactation with Baladi goats consuming a 45% concentrate diet at a level of intake presumably less than ad libitum. Performance was monitored for the entire trial, but it is unclear how frequently variables were measured, as is also the case for assessment of rectal temperature and respiration rate once daily at 12:00 h. The study was conducted under standard production conditions, with temperature-humidity index (THI) treatments of less than 70, 70–80, and greater than 80 through groupings of months of 1–2, 3–4, and 5–6, respectively. Even though THI was confounded with the stage of lactation, milk yield was lower for the highest than lowest THI treatment (1.61, 1.45, and 1.17 kg/day in months 1–2, 3–4, and 5–6, respectively), in accordance with greater respiration rate and rectal temperature for high vs. low THI as well. Respiration rates (24, 25, and 37 breaths/min for low, moderate, and high THI, respectively) do not, however, infer a high degree of heat stress. But, higher values later in the afternoon would be expected.

With increased fresh water intake under heat stress conditions, minerals present in the diet and water that could influence water intake may be important. Nguyen et al. (2018) conducted a study under moderate heat stress conditions with crossbred Saanen goats 3–4 yr of age and from wk 2–8 of lactation, with the first 2 wk for adaptation. Dietary levels of NaHCO3 and K2CO3 were varied for a cation exchange water intake may be important. Nguyen et al. (2018) conducted a study under moderate heat stress conditions with crossbred Saanen goats 3–4 yr of age and from wk 2–8 of lactation, with the first 2 wk for adaptation. Dietary levels of NaHCO3 and K2CO3 were varied for a cation exchange difference (DCAD) of 22.8 and 39.1 mEq/100 g DM. A DCAD of 30–40 mEq/100 g DM is common for lactating dairy cows (Linn 2018). Average THI at 07:00, 13:00, and 19:00 h was 78.1, 85.5, and 81.3, respectively. The diets were 44% corn silage and the NDF concentration was greater than might have been expected at approximately 51%. The high DCAD diet markedly increased water intake and total body water by 16%. This appears to have contributed to a slightly lesser rise in rectal temperature between 09:00 and 13:00 h, though there was no effect at other times. Intake of DM tended to be 16.5% greater for the high DCAD diet compared with the control, but neither milk yield nor composition differed. Nonetheless, it was concluded that increased water intake and balance due to high DCAD would be advantageous with moderate heat stress. The difference in feed intake without corresponding change in milk yield suggests lower efficiency of milk production for the high DCAD diet, although BW change was not reported. It is possible that digestibility was lower for the high DCAD diet because of a shorter ruminal digesta residence time resulting from increased feed and water intake. Although, a fairly large effect would have been necessary, such as a decrease from 65% to 56% OM
digestibility. Future experiments should include control treatments without heat stress and perhaps greater degrees as well.

Potential benefits of supplemental vitamin E and yeast culture with three first lactating Saanen goats (30 kg BW) subjected to heat stress were explored by Wang et al. (2016) with a $3 \times 3$ Latin square and 14-day periods. Goats were fitted with catheters in portal and mesenteric veins and a carotid artery. Neither stage of lactation nor milk production were specified, although DM intake was 5% BW or greater despite individual housing in metabolism cages and temperature at 35°C from 08:00 to 20:00 h and 24°C at other times. Nonetheless, in some manner, vitamin E decreased endotoxin absorption, which presumably was elevated with the control diet because of increased blood flow to extremities for heat dissipation and decreased flow in gastrointestinal tract tissues that adversely impacted the integrity of the intestinal epithelium. Moreover, vitamin E increased total antioxidant capacity in plasma and decreased malondialdehyde concentration. Conversely, plasma superoxide dismutase concentration was greatest for the control treatment, which was suggested to have resulted from increased synthesis to counter the greater need with elevated endotoxin absorption. Supplementation yeast had similar effects but of lesser magnitude than those of vitamin E. These results are deserved of future addition with a greater number of animals, a longer study period, less restrictive housing settings, and other heat stress conditions including a thermoneutral zone control treatment.

Fenugreek seed added at 50 or 100 g/day to a 45% concentrate diet consumed by Baladi goats of Egypt for 3 months beginning at 42 DIM also had numerous beneficial effects with moderate heat stress (El-Tarabany et al. 2018). Average daily THI ranged from 84 to 87. Though feed intake was not affected by fenugreek level, milk yield was increased by 8% and 34% with the 50 and 100 g/day levels, respectively. However, milk fat concentration decreased with increasing fenugreek level (3.61%, 3.42%, and 3.08%) so that milk fat and lactose concentrations decreased with increasing fenugreek level (3.61%, 3.42%, and 3.08%) so that milk fat yield was not markedly different among treatments (57, 58, and 65 g/day for 0, 50, and 100 g/day, respectively). Conversely, milk protein concentration was increased by 0.39 and 0.55 percentage units with 50 and 100 g/day of fenugreek seed, respectively. There were effects on numerous physiological measures, including increased blood levels of globulin and threonine and decreased concentrations of triglycerides, cholesterol, triiodothyronine, and catalase and increased total antioxidant capacity as well. Fenugreek contains a large number of bioactive substances (alkaloids, flavonoids, saponins, tannins, and phytoestrogens), preventing clear identification of factors responsible for change in specific variables. Furthermore, it would be of interest to determine if such favourable effects would occur with thermoneutral zone control treatments.

6. Dietary feedstuffs

6.1. Concentrate

Dietary levels of concentrate and forage receive much research attention, sometimes without a great deal of consideration for actual components of these feedstuff classifications. With feed accounting for such a high portion of the cost of production, considerable research with byproducts and nonconventional feedstuffs continues to be conducted. One such study is that of Tsilpakou et al. (2017b) with 3-year-old Alpine × Greek native goats over a 42-day period, without specification of DIM. Diets were 50% concentrate, with starch and neutral detergent fibre (NDF) levels of concentrate varied by partial substitution of sugar beet pulp and sunflower meal for corn. Diets were fed at approximately 4.4–4.7% BW for similar milk yield and to prevent refusals so that the diet consumed was the same as that offered. Based on total dietary levels of NDF of 45.6% and 51.5% in high and low starch diets, respectively, and levels in individual feedstuffs, total dietary levels of alfalfa hay and wheat straw were approximately 15% and 35%, respectively. There were no treatment effects on variables such as milk yield and levels of major constituents of fat, protein, and lactose or protein fractions impacting clotting properties, although there were small differences in levels of some individual FA in milk fat. It was concluded that byproducts high in ruminally degradable fibre could be substituted for cereal grains without appreciable effects. However, this would seem highly dependent on the overall nature of the diet. Although fibre requirements of lactating dairy goats are less well understood than those of dairy cattle, NDF provided by forages in this study would be much greater than minimums for dairy cattle (NRC 2001), suggesting that results could markedly differ with less total and forage NDF levels.

A mixture of byproduct feedstuffs available at a location in Spain was evaluated by Romero-Huelva et al. (2017) with Murciano-Granadina goats in mid-lactation. Byproducts included in the diet at a total level of 47% were tomato fruits, citrus pulp, brewer’s grain, and brewer’s yeast, fully or partially replacing corn, wheat bran, sunflower meal, and soy flour in the 41–43% forage diets. Concentrations in DM consumed by control and byproduct animals were 17.1% and 16.8% CP and 38.6% and 37.0% NDF, respectively. Intake of DM was similar between treatments, averaging approximately 3.4% BW, and digestibilities did not differ between treatments. But, the byproduct diet had numerous positive effects, such as increased N balance and retention that corresponded to an ADG difference of approximately 72 g (−36 vs. 36 for control and byproduct diets, respectively), decreased methane emission, increased molar percentage of propionate in ruminal fluid, and increased milk total protein and casein concentrations. The FA composition of milk from goats fed the byproduct diet also was improved in regards to potential human health effects. There were no definitive explanations stated for many of the effects given the number and nature of variables characterized. However, it was suggested that this blend of byproducts resulted in a more favourable amino acid profile than the control diet, although it is not clear if presumable extensive ruminal degradation of protein with both diets was considered. Moreover, it was postulated that the byproduct diet yielded greater synchrony in ruminal degradation of protein and energy availability for microbes, which could relate to lower ruminal ammonia-N concentration for the byproduct diet collected before the morning meal. But, because extensive ruminal N recycling minimizes the importance of fermentation synchrony in other livestock species (Cole and Todd 2008; Hall
and Huntington 2008; Reynolds and Kristensen 2008) as well as goats (Animut et al. 2002; Abebe et al. 2004; Soto-Navarro et al. 2003, 2004, 2006a, 2006b), perhaps treatments differed in the temporal pattern of nutrient availability that influenced peripheral tissue accretion as suggested earlier for the study of Silva et al. (2018). Though not characterized, it was theorized that plant secondary metabolites (PSM) in the byproducts may have decreased methane emission, corresponding to greater propionate production. But, the molar percentage of acetate also tended to be greater for the byproduct diet and that of butyrate was lower. The difference in milk FA composition was suggested to have been due to differences in the FA profile between the byproducts and more conventional feedstuffs that were replaced as well as an increased quantity of bioactive CLA isomers reaching the mammary gland to decrease de novo synthesis of short and medium chain FA. Future research should consider aspects such as the basis for specific byproduct levels selected, earlier and later stages of lactation, other byproduct levels, and perhaps some treatments with a lesser number of byproducts to allow discernment of factors primarily responsible.

Dates are produced in many areas of the world, particularly the Middle East. Date seeds or pits often are discarded but can be used in ruminant diets if physically processed. For example, AL-Suwaiegh (2016) fed 20 Ardi goats of Saudi Arabia diets with 60% alfalfa hay containing 0, 10, 15, or 20% date pits, with concentrate ingredients varied for similar CP and NDF levels of 14–15% and 42–44%, respectively. The dietary level of date pits had negligible effect on DM intake (1.45–1.48 kg/day), milk yield (1.39–1.43 kg/day), and milk protein concentration (2.43–2.57%). Low DM intake relative to BW (2.40–2.50% BW) may relate in part to typical average temperature and humidity in the 2 months when the trial occurred reported to be 48°C and 90%, respectively. Moreover, it was stated that feed refusals were limited to 1–2% of the amount offered, which could have restricted intake. Even though the level of fat in date pits was 7% and the total dietary level varied only from 2.3% to 2.7%, numerically milk fat percentage and yield decreased with increasing level of date pits from 3.7% to 2.9% and 52–40 g/day, respectively. Responsible factors are unclear, although an effect on digestibility is conceivable depending on factors such as the nature and extent of physical processing. Lastly, though date pits do contain PSM such as tannins, there were no clear adverse effects of date pit inclusion or level in the diet indicated by blood constituent levels. Sharifi et al. (2017) noted somewhat more favourable results with Saanen goats at 97 DIM consuming 45% forage diets with 0%, 6%, 12%, or 18% date seeds substituted for wheat bran. Intake of DM was not affected by date seed level, but 4% fat-corrected milk yield tended to increase linearly with increasing date seed level from 1.59 to 1.79 kg/day. Presumably because of antioxidants in date seed such as phenolics, the total antioxidant capacity of milk and blood increased linearly with the increasing level of date seed. Conversely, levels of malondialdehyde in milk and blood and levels of superoxide dismutase and glutathione peroxidase in blood were similar among diets perhaps because of little to no differences among diets in oxidative stress elicited. Because of oil present in palm seed in contrast to the lower level in palm kernel meal, there were effects on milk FA levels, some favourable and others not regarding human health effects, including linear increases with increasing date seed level in concentrations of C18:0, C18:1, and the CLA isomer cis-9 trans-11 C18:2 (rumenic acid), and a decreasing concentration of total polyunsaturated FA.

Methods of processing foods for human consumption can change over time, an example being relatively more olive oil in Turkey derived via a two-phase process that results in high levels of sugar and phenolics than three-phase extraction. Keles et al. (2017) conducted a study in which olive cake from this processing method was included at 0%, 10%, or 20% in the diet of Saanen goats in late lactation. The cake replaced barley so that the dietary NDF concentration increased with increasing olive cake level from 46 to 53–54%. There were not clear or marked effects of cake level on feed intake, and milk yield was similar among treatments as well. Perhaps because of somewhat high levels of forage and NDF and the late stage of lactation, the ratio of milk yield to DM intake was relatively low (i.e. 0.46–0.54). Milk fat concentration increased markedly with increasing olive cake level from approximately 3.75–4.45%, presumably because of increasing dietary levels of ether extract. There were a number of effects of olive cake level on FA composition resulting in a decreasing atherogeneity index with increasing level of cake that could relate to FA in olive cake and perhaps effects of phenolic compounds on completeness of ruminal biohydrogenation as well.

The byproduct glycerin or glycerol is readily available in many areas because of the growing biodiesel industry. Thoh et al. (2017) fed 12 crossbred goats (75% Saanen and 25% Thai native) at 60 DIM diets with 0%, 5%, or 10% crude glycerin substituted for corn. There were no significant effects of glycerin level on DM intake or milk yield. The only major effect on milk composition was an increase in fat with the 5% level, although the control treatment fat level was relatively low at 2.46%. Moreover, dietary concentrate and forage levels are unclear, since if concentrate was offered at 50% of milk yield as stated, it would have accounted for nearly all DM consumed, concomitant with a very high ratio of milk yield to DM intake of 1.76–1.90. Hence, ad libitum forage intake may not have been considered in the feed intake values presented. Nonetheless, there were some diet effects on milk physicochemical properties, which contributed to the conclusion that the glycerin level of 5% was advantageous compared with inclusion at 10%.

Kir et al. (2017) evaluated the dietary substitution of pumpkin seed cake for soybean meal with French Alpine goats in early lactation, and there was a third diet in which linseed meal partially replaced soybean meal. There were no differences in milk yield or composition between the soybean meal and pumpkin seed meal diets. However, the linseed meal diet elicited a number of favourable changes in milk FA composition in terms of human health conditions. In contrast to some findings with linseed oil addition to the diet, the linseed meal diet increased levels of odd- and branched-chain FA, suggesting an increased contribution of bacterial FA from change in growth rate or specific types of bacteria.

With the considerable increase in the global population expected in the next few decades, there is considerable interest in novel protein sources for direct consumption by humans as well as inclusion in livestock diets. Various insects and other
substances such as defatted marine microalgal biomass have received greatest attention, although very little research has been conducted with ruminant livestock. Recent reviews in the area of novel protein sources include Lum et al. (2013), Makkar et al. (2014), Anankware et al. (2015), Stamer (2015), Akhtar and Isman (2018), and de Castro et al. (2018).

6.2. Fibrous feedstuffs

There has been considerable research with leaves of the Moringa oleifera (MO) tree in the last few years, most with very promising findings. For example, Kholf et al. (2016) fed lactating Anglo-Nubian goats 40% berseem hay diets with sesame meal at 20% for the control and 5% in others with MO in fresh, hay, or silage forms included at 15%. Dry matter intake was greater for fresh and silage MO diets than for control and hay. Although, DM intake for all diets relative to BW was low (2.14–2.40% BW) despite refusals stated to have been present, which may relate to the unspecified stage of lactation and age or possibly low BW for this breed (36.2 kg). Digestibility of OM averaged 3.9 percentage units greater for diets with than without MO. The ammonia-N concentration in ruminal fluid was decreased by MO inclusion, although the unit indicated is unclear (i.e. 24.3–30.9 g/l). Energy-corrected milk yield ranked fresh and silage > hay > control, but with the greatest difference being only 0.23 kg/day. Likewise, milk fat concentration was greater for fresh and hay vs. control and silage diets; however, the average difference was 0.24 percentage units. There were also favourable effects on milk FA composition, with improvements in atherogenicity index that were greater for the fresh and hay diets than for silage compared with the control treatment. Some of the changes were postulated to have been caused by the relatively low ruminal degradability of protein in MO and phenolic compounds and tannins in MO, yet dietary levels attributable to MO were only 0.66 and 0.30 percentage units, respectively.

Babiker et al. (2017) noted enhancements of numerous variables from feeding MO leaves, similar in some respects to results of Kholf et al. (2016). Aardi goats of Saudi Arabia that had been lactating for 3 months were fed a control diet with 40% alfalfa hay or one with 25% MO leaves and 15% alfalfa hay, with 2 kg/day of diets offered to each animal. The NDF concentration in alfalfa hay and MO leaves was 27.0% and 20.9%, respectively. Milk yield was greater for the MO leaf diet (5.34 vs. 3.46 kg/day), although this corresponds to a very high milk yield to DM intake ratio. Milk fat concentration was slightly greater for the MO leaf diet and there were improvements in many antioxidant status indicators of serum and milk. Even the growth rate of kids was greater for the MO leaf vs. control diet (e.g. 183 vs. 164 g/day). Likewise, very positive results were reported by Kholf et al. (2018) from oral doses of an extract from MO leaves. Nubian goats in early to mid-lactation consumed a 40% forage (berseem clover) diet; however, BW and DM intake relative to BW again appeared lower than expected (initial BW of 36.5 kg and DM intake of 2.1–2.3% BW). Nonetheless, it was postulated that bioactive compounds in the extract were responsible for increases in feed intake, digestibility, and total volatile fatty acids (VFA) and propionate concentrations in ruminal fluid.

Maralfalfa (Pennisetum sp.) is a forage of interest with some harvested forage production systems because of its high potential DM yield and nutritive value depending on management practices. Criscioni et al. (2016) fed Murciano-Granadina goats in late lactation diets of 1 kg of alfalfa hay or maralfalfa hay harvested at 70 days of growth along with 1.5 kg/day of concentrate. Alfalfa and maralfalfa were 16.1% and 14.4% CP, 52.2% and 61.0% NDF, and 11.8% and 3.6% ADL, respectively. Total DM intake was greater for alfalfa vs. maralfalfa (1.8 vs. 1.6 kg/day), which corresponded to greater refusal of maralfalfa with complete concentrate consumption. With the higher dietary concentrate level for the maralfalfa diet, probably longer ruminal digesta residence time, and greater fibre lignification, digestibilities and the ruminal fluid molar percentage of propionate were greater than for the alfalfa diet. The efficiency of ME utilization for lactation was slightly greater for the alfalfa diet but factors responsible were not readily apparent. Concentrations of most milk constituents were similar between treatments but levels of C15 and C17 FA were greater for maralfalfa, presumably because of a difference in propionate availability. Ruminal methane emission relative to feed intake was similar between diets. Overall, the results show promise in use of this type of forage in diets of lactating goats. Future attention should be given to earlier stages of lactation and similar and lower dietary levels of concentrate for clearest potential interpretation.

Lopes et al. (2017) investigated different levels of replacement of Tifton bermudagrass hay with alfalfa hay (0%, 33.3%, 66.7%, and 100% of the dietary level of 30%) in diets with 40% spineless cactus of multiparturant dairy goats producing approximately 3 kg/day of milk. Feed intake was greater with than without alfalfa hay included in the diet, with no effects on milk yield or composition or most other variables. But, there was a quadratic effect of replacement level on NDF intake, and with regression analysis, it was concluded that the 43.8% substitution level, corresponding to a total dietary NDF level of 34.2%, was a transition point. With lower levels of substitution and higher NDF concentration (37.5%, 35.1%, 32.4%, and 29.9% for alfalfa levels of 0%, 33.3%, 66.7%, and 100%, respectively), it was proposed that feed intake was controlled by ruminal digesta fill vs. energy intake with lower dietary NDF and higher alfalfa levels. Although this is certainly possible, more research regarding minimal, maximal, and optimal dietary NDF levels for dairy goats is needed. The dietary levels of total and forage NDF for the 100% alfalfa hay replacement level were adequate in regard to recommendations of NRC (2001) if at least a low portion of spineless cactus is considered. For example, if cactus is classed as 17% forage and 83% non-forage, the 9.4% NDF in the diet from cactus would have contributed 1.6% forage NDF, for a total dietary level of 16.5% NDF from forage (i.e. 14.9% from alfalfa), which corresponds to a minimum total dietary NDF level of 30% for dairy cattle (NRC 2001).

Fernández et al. (2018) used Murciano-Granadina goats in late lactation to evaluate dietary inclusion of pelleted lemon leaves compared with alfalfa pellets. The diets consumed were 33% and 35% lemon leaves and alfalfa, and with the lower level of NDF in lemon leaves (26% vs. 49%), the NDF concentration in DM consumed was 20.0% and 28.2%, respectively.
The NDF level for the diet with lemon leaves is appreciably lower than recommended for dairy cattle (NRC 2001). Nonetheless, milk energy yield was similar between treatments and ruminal methane emission was slightly lower for lemon leaves vs. alfalfa (4.5% vs. 5.7% of digestible energy intake). The methane difference was explained by a higher lipid content in lemon leaves (3%, inclusive of essential oils). However, it would seem plausible that the low dietary fibre level had impact, as supported by a difference in total tract NDF digestibility (18.4% and 32.5% for lemon leaves and alfalfa, respectively). Ruminal pH of 7.0–7.1 determined by stomach tube samples before the morning meal would not seem to discount adverse effects on fibre digestion of low ruminal pH as well as preferential starch utilization by fibrolytic bacteria.

7. Dietary inclusion of fat and oil

Dietary inclusion of various sources of fat and oil to influence the level and composition of milk fat continues to receive considerable attention relating to milk fat depression, human health effects, and processing mainly into cheese. Regarding milk fat depression, Bernard et al. (2017) fed multiparous Alpine goats diets without added oil or with 2.2% fish oil or 5.3% sunflower oil plus wheat partially substituted for corn, yielding NDF concentrations of 36%, 35%, and 30%, respectively. The sunflower oil and wheat treatment did not influence milk fat. As has been noted previously with goats, though with less effect compared with dairy cattle, milk fat concentration and yield were decreased by fish oil from 3.11% to 2.47% and 77–62 g/day, respectively. Such effects have been explained by a number of factors, one being incomplete ruminal biohydrogenation of FA resulting in bioactive intermediates, notably the trans-10, cis-12 CLA isomer, reaching the mammary gland that inhibits de novo FA synthesis. Other contributing conditions are decreased availability of C18:0 in the mammary gland and factors influencing FA removal from epithelial cells. In a similar study addressing bacterial populations of both dairy cattle and goats (Toral et al. 2016), ruminal biohydrogenation pathways with the sunflower oil and added starch diet were less affected with goats, suggestive of species differences in the microbiota contributing to unique responses to dietary fat treatments. Previously species differences were thought mainly attributable to lower susceptibility of mammary gland enzymes of goats. Numerous factors could be responsible for differences in ruminal microbial populations in dairy goats and cows even when consuming the same diets, including a greater level of intake by goats relative to BW and shorter ruminal digesta residence time as well as varying pre-trial conditions.

Bernard et al. (2016) used multiparous Alpine goats at 89 DIM to evaluate the potential for improving health benefits from milk consumption by addition of a relatively high level of extruded linseed oil (11–12%) to diets containing fish oil at 1.2–1.3%. Moreover, different ratios of barley, wheat, and beet pulp were used to vary starch concentration and rate of fermentation. Although there were some beneficial changes in levels of specific FA from linseed oil inclusion when expressed in g/g FA, milk fat concentration was relatively low for all treatments at 2.43–2.96%. This high level of linseed oil caused only a small increase in fat concentration (i.e. 2.81 vs. 2.63%). Likewise, the high dietary starch level due to wheat inclusion elicited small decreases in milk fat without and with extruded linseed oil (i.e. 2.43% vs. 2.74% and 2.61% vs. 2.91%, respectively). Similarly, Inglingstad et al. (2017) noted favourable effects of rape-seed oil in diets of Norwegian dairy goats on levels of total fat and polyunsaturated FA, as well as lower lipoprotein lipase activity in milk that positively affected flavour score.

The dietary level and type of oil added can have effects apart from milk fat concentration and FA composition. One aspect addressed by Tsiplakou et al. (2017a) is the effect on conditions relating to oxidation. Alpine crossbred dairy goats at 90 DIM were fed a 50% concentrate diet with or without 2.5% soybean oil and 0.5% fish oil, although it appeared that intake was not ad libitum. Oils were included in regard to their potential to increase plasma lipid peroxidation and oxidative stress, although it was noted that both oils provide antioxidant capacity. Oil inclusion increased plasma activity of the antioxidant enzymes catalase, glutathione reductase, and glutathione transferase and ferric reducing or total antioxidant activity. But, because plasma malondialdehyde and protein carbonyl levels were increased as well, it could not be discerned if increased antioxidant capacity resulted from antioxidants provided by oils or was caused by increased oxidative stress. This is somewhat different from findings of Sharifi et al. (2017) with increasing dietary level of date seeds overviewed earlier, with increased antioxidant capacity and no differences in indicators of oxidative stress. Such findings suggest need for studies addressing these potential counteracting human health effects of supplementing lactating dairy goat diets with polyunsaturated FA.

With considerable impact of the FA composition of the diet on that in milk, there is interest in sources of oil naturally high in CLA, a notable example being oil of pomegranate seed. Emami et al. (2016) fed Mahabadi goats in mid-lactation diets without added oil or with 2.5% of pomegranate or linseed oil. There were no deleterious effects of oil supplementation on intake or digestion, but the concentration of milk fat was increased by both oils. The oils each had favourable effects on FA composition of milk fat in regards to human health, such as decreased saturated FA and increases in mono- and polyunsaturated FA and the total CLA level. Moreover, because of polyphenols in pomegranate seed oil, total antioxidant capacities of milk and blood were increased converse to decreases elicited by linseed oil (Emami et al. 2017). Likewise, pomegranate seed oil decreased and linseed oil increased milk and plasma levels of malondialdehyde.

Because most odd- and branched-chain FA in milk originate from bacterial lipids, total amounts have been used as general indicators of ruminal microbial activity. Moreover, since concentrations of the specific FA vary among different types of bacteria, their levels may allow characterization of the nature of the diet. Cívico et al. (2017) used milk concentrations of odd- and branched-chain FA fairly effectively to differentiate between diets varying in types of feedstuffs in concentrate (i.e. soybean hulls vs. corn and barley) and linseed oil inclusion. However, because some different conditions can have similar effects on types of bacteria such as the decreased prevalence of fibrolytics and an increased level of starch digesters due to
low pH or supplemental FA, use of milk levels of other FA may be required. Similarly, Inglingstad et al. (2017) noted higher levels of odd- and branched-chain FA in the milk of goats receiving a control concentrate compared with addition of 8% hydrogenated palm oil or 8% rapeseed oil presumably partially because of adverse effects of oil on ruminal microbial activity, and decreased de novo FA synthesis in the mammary gland may have occurred as well.

8. Dietary additives and plant secondary metabolites

Ruminal microbial populations may have potential to adapt over time to effects of some bioactive additives. Thus, findings may differ between studies with short and longer feeding periods. Relatedly, adaptation to the ionophore monensin has been observed in some beef and dairy cattle experiments. Li et al. (2017) studied this aspect with nonlactating Xinong Saanen goats limit-fed a 60% forage diet at an average DM intake of 1.85% BW in a 55-day trial. The effect of monensin on ruminal methane emission decreased markedly as the study progressed and also with advancing time during the 10 h between morning and afternoon meals. It would be of interest to conduct a similar experiment under other conditions, such as greater DM intake, a lower level of monensin of 22 mg/kg DM rather than 32, and a true control treatment to avoid confounding with time. Relatedly, in an experiment with mature Boer goat wethers and a diet based on alfalfa hay consumed ad libitum for 20 wk (Puchala et al. 2018), effects of monensin at 22 mg/kg DM on ruminal methane emission were similar in wk 5, 10, 15, and 20. Likewise, the effect of condensed tannins primarily from lespedeza on ruminal methane emission by yearling Alpine doelings, compared with alfalfa hay, was similar after 6 and 12 wk (Liu et al. 2019).

Kholif et al. (2017a) theorized that because of different general modes of action, effects of commercially available live yeast and exogenous enzyme products could be synergistic. Nubian does with a BW of 35.1 kg were used in a Latin square study with 22-day periods. Products were included in the 60% concentrate diet alone or together. Though effects were not synergistic, each product positively affected a large number of variables including DM intake (i.e. 2.22% and 2.40% BW for diets without and with additives, respectively) and milk yield (0.88–1.00 kg/day) and fat concentration (3.2–3.6%). Digestibilities of many dietary fractions were increased as well, although pooled treatment SEM were low, some magnitudes of treatment differences were not marked, and CP digestibility was much less than expected based on the relationship proposed by Moore et al. (2004; i.e. 58.0–61.5 vs. 72.7%). With responses to such products not always observed, research with longer feeding periods, other diets, and animals with greater BW, DM intake, and milk yield would be beneficial.

Though most attention has been given to effects of condensed tannins in ruminant diets, Abo-Donia et al. (2017) added different levels of hydrolysable tannins from gallnut to the diet of Liuyang black goats (26.3 kg BW) also containing 1.9% rapeseed oil. It was postulated that the tannins would inhibit activity of ruminal bacteria performing the last step of biohydrogenation of trans-11 C18:1 (vaccenic acid), thereby increasing its concentration in milk, as well as increasing the level of cis-9 trans-11 C18:2 by decreasing biohydrogenation of polyunsaturated FA or increasing mammary gland desaturation of trans-11 C18:1 (Tsiplakou and Zervas 2008). However, there were only some minor improvements in the milk FA profile. Dietary factors to study in future research are the dietary level of oil, tannin nature, and dietary fibre level in regard to the reported NDF concentration of 19% despite maize stover included at 45%.

Essential oils are being studied as alternatives to ruminal modifiers such as ionophores because of their ban in some countries but also relating to other potential unique effects. However, there is a wide array of essential oils and multiple ones present in many plants and plant parts. In this regard, Canaes et al. (2017) included citral oil, the primary essential oil in lemongrass (Cymbopogon citratus), at 0, 0.08, 0.16, or 0.24 ml/kg BW in a 50% concentrate diet fed to Saanen goats in a Latin square study with 21-day periods starting at 75 DIM. There was no effect on feed intake but a linear decrease in NDF digestibility with increasing level of citral oil occurred, although values were quite low relative to digestibilities of other fractions (34.9–43.3% vs. 74.0–75.5%). Citral oil level impacted molar percentages of some VFA in ruminal fluid and blood urea concentration. There were no changes in levels of enzymes in blood reflecting liver function, milk yield, or milk fatty acid levels. Fat-corrected milk yield tended to decrease linearly with increasing citral oil level, but uncorrected milk yield relative to DM intake was relatively high at 1.53–1.70:1. Overall, there were no clear appreciable benefits from use of citral oil, which may relate to the variety of conditions that could be influenced by essential oils such as citral oil, which include altered numbers and(or) specific types of ruminal microbes, liver function, blood flow, membrane permeability, antioxidant status, etc.

There are many potential dietary ingredients that contain more than one bioactive substance, increasing the likelihood of variable responses and deeming experimentation with a variety of conditions desirable. For example, Kholif et al. (2017b) included lemongrass or rosemary herbs at 0 or 10 g/day in the diet of lactating Damascus goats in a 12-wk study starting the first week of lactation. There were numerous beneficial effects of dietary inclusion of both herbs, with both increasing milk yield and improving the profile of milk FA in regards to human health status. Digestibility of OM was increased, but differences were only 2.1 and 3.1 percentage units with five observations per treatment and a pooled SEM of 0.51%. Morsy et al. (2018) conducted a similar study with Damascus goats in early lactation consuming diets providing 0 or 10 g/day of dried mustard or cumin seed, both also containing a variety of bioactive compounds, including essential oils, saponins, and tannins. The seeds resulted in many desirable effects, among which are increases in OM digestibility, total VFA concentration and the molar percentage of propionate in ruminal fluid, milk yield in kg/day and relative to DM intake, and milk levels of unsaturated FA and CLA and decreased saturated FA. Factors responsible for the milk FA changes were suggested to include effects of bioactive seed components on ruminal biohydrogenation that resulted in increased amounts of bioactive CLA isomers reaching the mammary gland.
However, it should be noted that DM intake was only 2.55–2.60% BW despite 50% of the diet being berseem clover and a total dietary NDF level of 36%. Furthermore, reported ruminal pH at 3 h after the morning meal was 5.05–5.15, yet NDF digestibility was 61–64%. Future research attention with these and other herbs should consider different experimental and production conditions such as level of dietary inclusion. For example, herb and seed levels of Kholif et al. (2017b) and Morsy et al. (2018) were 0.023% BW compared with much higher levels of citral oil used by Canaes et al. (2017) of 0.08–0.24 ml/kg BW. Moreover, specific factors responsible for changes should be identified, as without such information conditions and settings to which such findings can be extrapolated are unclear and long-term research progress will be limited.

9. Conclusion

Dairy goats have considerable capacity for tissue mobilization to support milk production, but appreciable levels would necessitate a high nutritional plane later for replenishment. Management practices in gestation should control tissue mobilization to facilitate use in early lactation when required for high milk yield. Dairy goats have very flexible feeding behaviour, but there is need for additional research to more fully understand potential influences on level and efficiency of production. There is considerable opportunity to minimize production costs by taking advantage of the wide array of materials that goats will voluntarily consume through extensive use of regionally available byproducts and nonconventional fibrous feedstuffs. Although in most cases environmental conditions are less severe than for goats reared for other purposes such as meat production, with climate change resilience to more extreme conditions should be considered. In addition to continuing research of the effects of dietary inclusion of various sources of fat and oil on milk yield and FA composition, increasing attention is being given to antioxidant conditions, as is also the case for dietary inclusion of substances such as essential oils. However, experimental design considerations should be made so that modes of action are determined and results can be extrapolated to other settings.

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