Can Tho University Journal of Science
website: ctujs.ctu.edu.vn

DOI: 10.22144/ctu.jen.2022.047

Nutritional value and factors affecting milk production and milk composition from dairy sheep: A review

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Article info.

Received 30 Mar 2022
Revised 20 May 2022
Accepted 31 May 2022

Keywords

Body condition score, dietary nutrient, milk fat, milk protein, milk yield, sheep milk composition

ABSTRACT

Sheep milk contains much higher concentrations of protein, fats, minerals, and vitamins than milk from other common domestic species such as cows and goats. High nutritional value and lower allergic sensitization compared to cow milk make sheep milk an ideal source of nutrition for humans. Moreover, advantages in physicochemical characteristics also make sheep milk a very good raw material for processing, especially in cheese making. However, dairy sheep industry remains small in many regions of the world, mostly due to restricted genetics and limited milk production. Milk yield and composition are influenced by various factors including genetic parameters, dietary nutrient composition, parity, lambing season, milking frequency, and stage of lactation. Future research on dairy sheep in different production systems especially in developing countries and new genes regulating milk production and quality need to be undertaken.

1. INTRODUCTION

Sheep have been raised for milk for 11,000 years even before cows. However, the dairy sheep industry has remained small with limited productivity compared to the dairy cow industry (Table 1). According to the Food and Agriculture Organization of the United Nations (FAOSTAT, 2018), there are approximately 250 million dairy sheep worldwide, accounting for 20.8% of the total sheep population (Pulina et al. 2018). In 2019, 10.56 million tonnes of sheep milk were produced (FAOSTAT, 2019), representing only 1.3 % of worldwide total milk production. Cheese is the major processed product manufactured from sheep milk, with worldwide production of 702.8 thousand tonnes in 2019 (FAOSTAT, 2019). The demand for sheep milk and its processed products is rapidly increasing, and dairy sheep offer advantages over dairy cows in terms of environmentally and climate-friendly production. Therefore, it is expected that worldwide dairy sheep production will increase by 26% (approximately 2.7 million tonnes) in the next decade (Pulina et al., 2018). The aim of the present review is therefore to provide an update on the published literature on nutritional value, the factors that affect milk yield, and the composition of sheep milk. Outcomes from this review will open up the opportunity for further research on enhancing the production and altering sheep milk composition contributing to enhancing the economic benefits for dairy sheep producers and finally benefit for the whole industry.

Table 1. World overview of dairy sheep, goats, and cows

Dairy animals	Population (Million head)	Milk production (Million tonne)	Yield (L/head)
Sheep	250	10.37	41.5
Goats	203	15.26	75.3
Cows	600	600	2,200

Source: FAOSTAT (2018)

2. DAIRY SHEEP INDUSTRY BACKGROUND AND THE CONSTRAINTS FOR DAIRY SHEEP PRODUCTION

According to FAOSTAT (2018), most dairy sheep are raised in subtropical-temperate zones in Asia, Africa, and Europe with 135, 7,9, and 13.3 million head respectively (Figure 1 a). Asia is dominant over all regions in total milk production (Figure 1 b), while Europe has the highest average milk yield (Figure 1c).

Although milking sheep have been undertaken in other continents including America and Oceania for more than a hundred years, the dairy sheep industry in these continents remains small compared to the meat and sheep wool industries and to regions. Total milk production in the North and South Americas and Oceania together accounted for only 1% of total world production (FAOSTAT 2018). The lack of specialized breeds and typical sheep milk products compared to lamb meat and wool industries probably is the main reason for this in Oceania (Bencini, 1999). Apart from restricted genetics, lack of suitable infrastructure, limited milk production, and lack of institutional support for the industry contributed to the limitation of dairy sheep production in Americas (Pulina et al. 2018).

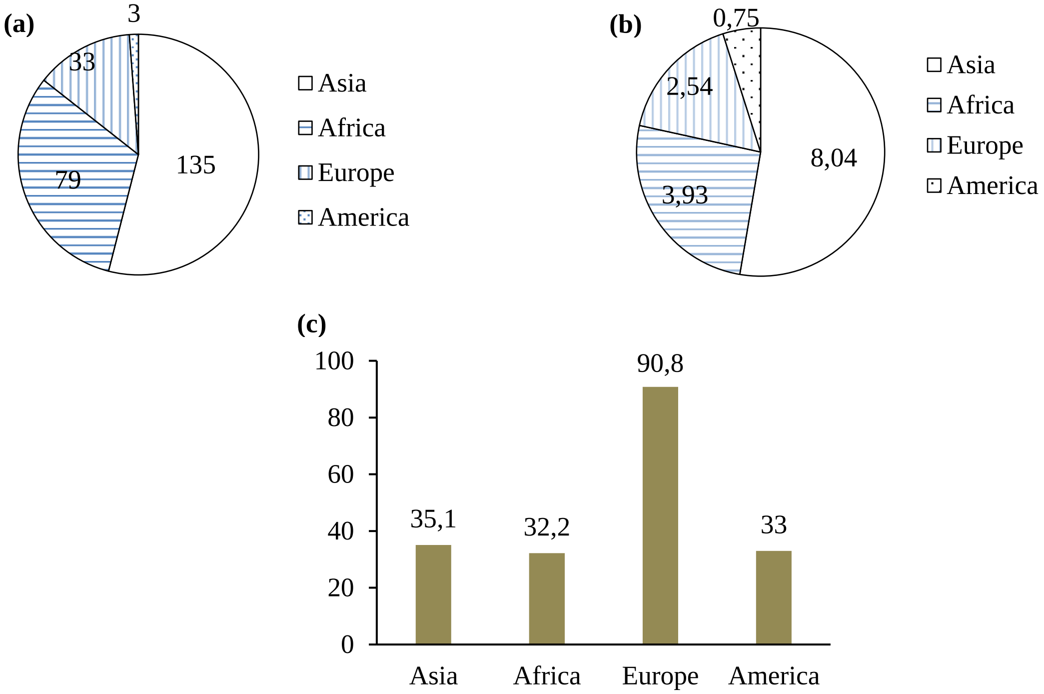

Figure 1. Total number of dairy sheep (million head) (a), total milk production (million tonne) (b), milk yield (L/head) (c) by continents (FAOSTAT 2018)

3. NUTRITIONAL VALUE

In comparison to milk from cows and goats, sheep milk is a richer source of fat and protein (Figure 2), and other vital micro and macro elements, particularly calcium (Park et al., 2007; Balthazar et al., 2017).

3.1. Milk fat

Fat is the most important component of milk defining its nutritional and energetic values. The fat content in milk from sheep is two times higher than in milk from goats and cows (Figure 2 a). It contributes a noticeably higher energy value of 105 calories/100 ml compared to 69 and 70 calories/100 ml in cow and goat milk (Park et al., 2007). Moreover, milk fat globule sizes from goats (3.0 µm) and sheep (3.6 µm) are smaller than those of cows (4 µm) (Gantner et al., 2015). Small size and high dispersion state result in easier access of lipolytic enzymes to fat globules, enabling easier digestibility for humans consuming sheep and goat milk than cow milk (Tomotake et al., 2006). These fat globule characteristics also have technical advantages in reducing phase separation under frozen storage conditions used for cheese production. In terms of fatty acid profile, similar to goat and cow, sheep milk contains mainly saturated fatty acids (SFA) varying from 57-75% in total fatty acids (Gantner et al., 2015). However, citing a number of authors, Markiewicz-Keszycka et al. (2013) concluded that the proportion of polyunsaturated fatty acids (PUFA) at 4.82% in sheep milk is higher than in cows and goats (4.05 and 3.70%, respectively). Similarly, sheep milk has a higher concentration of conjugated linoleic acid (CLA) compared to cow milk (1.08 and 0.65%, respectively). A significantly lower ratio of n-6 PUFA to n-3 PUFA (2.31, 5,00, and 6.01 for sheep, goat, and cow milk, respectively) (Markiewicz-Keszycka et al., 2013) makes sheep milk more desirable than cow and goat milk in inhibiting the risk of chronic diseases (Simopoulos, 2002; Zymon et al., 2014).

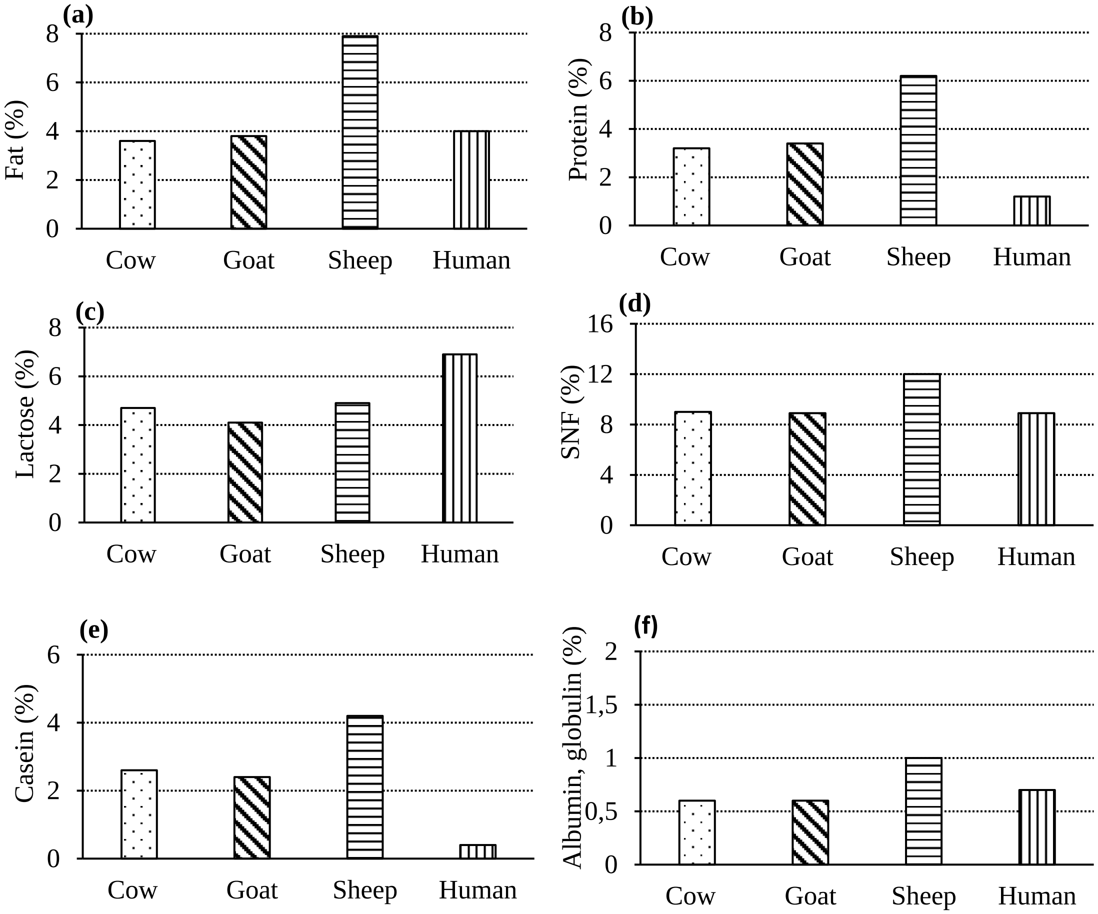

Figure 2. Fat (a), protein (b), lactose (c), solids-non-fat (SNF) (d), casein (e), albumin and globulin (f) percentage of milks from cow, goat, sheep and human (Park et al., 2007)

3.2. Milk protein

In comparison with cow milk, sheep milk contains a higher percentage of protein (5.8 vs 3.3%) (Park et al., 2007), of which 80% are casein complexes and the rest are whey protein fractions (Balthazar et al., 2017). This high concentration of casein is of benefit to cheesemakers due to a positive relationship between the casein content of raw milk and cheese yield (Colin et al., 1992; Hurtaud et al., 1995). Another structural advantage of sheep milk protein is that casein micelles have a rich calcium content that serves as a catalyst for rennet coagulation (Kethireddipalli & Hill, 2015), thus adding $CaCl_2$ is not required in sheep cheese making. Higher mineralization of casein micelles supports cheesemakers to produce adequate curd from sheep milk using less rennet or chymosin and still achieve the same coagulation time compared to cow milk (Kalantzopoulos, 1993). With regards to nutritional value, a higher protein concentration with lower allergic sensitization (Masoodi & Shafi, 2010) are attributes of sheep milk that make it an ideal alternative protein source for consumers who have an allergy to cow milk (Scintu & Piredda, 2007).

3.3. Minerals and vitamins

Sheep milk is the richest source of vitamins and additionally a source of some critical minerals compared to goat and cow milk (Table 2). Calcium and phosphorus, the main microminerals that affect the growth and maintenance of the skeletal structure, are much higher in sheep milk than in cow and goat milk. According to the National Health and Medical Research Council of Australia (NHMRC, 2013), 494 mg of calcium in one standard serving (494 mg/250 ml) contributes nearly half of the daily recommended intake of 1000 mg of calcium for adults (NHMRC, 2006). In humans, high protein intake was shown to elevate calcium absorption (Kerstetter et al., 2011), thus sheep milk that contains a high concentration of calcium and protein is considered as an effective dietary calcium supplement.

Table 2. Mineral and vitamin contents in sheep, goat, and cow milk

Items	Unit	Sheep	Goat	Cow
Mineral				
Ca	mg/100 g	197.5	130	112
P	mg/100 g	141	109	91
Mg	mg/100 g	18	16	12
K	mg/100 g	138	185.5	145
Na	mg/100 g	39	39.5	42
Cl	mg/100 g	160	150	100
S	mg/100 g	29	28	32
Fe	mg/100 g	0.08	0.07	0.08
Cu	mg/100 g	0.04	0.05	0.06
Mn	mg/100 g	0.02	0.03	0.007
Zn	mg/100 g	0.6	0.43	0.4
Se	µg/100 g	1.0	1.33	0.96
Vitamin				
Vitamin A	µgRE/100 g	64	54.3	37
Vitamin B_6	mg/100 g	0.08	0.046	0.042
Vitamin B_{12}	µg/100 g	0.712	0.065	0.375
Vitamin C	mg/100 g	4.16	1.29	0.94
Vitamin D	µg/100 g	0.2	0.2	0.15
Biotin	µg/100 g	2.5	1.75	2.0
Niacin	mg/100 g	0.416	0.27	0.08
Riboflavin	mg/100 g	0.376	0.21	0.16
Pantothenic acid	mg/100 g	0.408	0.31	0.32
Folic acid	µg/100 g	5.0	1.0	5.0
Thiamine	mg/100 g	0.08	0.068	0.045

(Sources: Park et al., 2007; Balthazar et al., 2017)

4. FACTORS AFFECTING MILK YIELD AND COMPOSITION

4.1. Genetic parameters

Although approximately 180 different sheep breeds produce milk for human consumption, only a few of these breeds are considered as primary "dairy" breeds (Table 3), with East Friesian (EF) and Awassi being probably the most popular (Park et al., 2017). Developed in northern Germany and the Netherlands and known as the world's most productive dairy sheep (Haenlein, 2007), the use of EF as purebred animals in unfavorable environmental conditions such as excessive heat and humidity is limited (Gootwine & Goot, 1996). Thus, EF has been used widely in crossbreeding systems to improve milk production and the prolificacy of local breeds. For example, EF rams were mated with Dorset-cross, Polypay, and Rambouillet ewes to improve the productivity of the local dairy sheep industry under dairy sheep production conditions in North America (Berger & Thomas, 1997; Thomas et al., 1998; Thomas et al., 2000). Following EF regarding milk production capacity, the Awassi is the most numerous and widespread breed of dairy sheep in the world because of its ability to adapt to diverse environmental conditions (Galal et al., 2008).

Table 3. Average lactation length, milk yield, and composition of common sheep breeds used for milk production

Breed	Original country	Lactation length (days)	Milk Yield (kg)	Fat (%)	Protein (%)	Total solids (%)	Ash (%)	Lactose (%)
East Friesian	Germany	300	632	6.5	5.25	17.0	0.9	4.9
Awassi	Israel	270	495	6.61	5.74	18.24	0.93	4.96
Lacaune	France	165	270	7.40	5.63	18.63	0.93	4.67
Chios	Greece	210	218	7.90	6.20	19.08	0.92	4.06
Sarda	Italy	200	158	6.99	5.60	18.14	0.95	4.60
Manchega	Spain	210	300	7.78	6.01	18.98	0.90	4.29
Churra	Spain	150	150	7.30	5.98	18.30	0.95	4.25

(Sources: Haenlein, 2007; Park et al., 2017)

Estimates of heritabilities and genetic correlations for major milk traits portrayed in Table 4 range from moderate for milk, fat and protein yields (approximately 0.25-0.30), to high for fat and protein content (0.50 to 0.60) (Park et al., 2017). Genetic improvement programs have been based on purebred selection and mainly implemented in Europe (Barillet, 2007) where milk, fat, and protein yields are major selection criteria (Carta et al., 2009) used by breeders. For instance, genetic programs employed for Lacaune in France contributed to annual increases of 0.12 and 0.14% in fat and protein contents, respectively, with an annual genetic gain of 5 liters in milk production (Astruc et al., 2002).

Table 4. Heritabilities and genetic correlations for lactating traits of different breeds

Trait	Milk yield	Fat yield	Protein yield	Fat (%)	Protein (%)
Milk yield	0.20 to 0.32	0.77 to 0.89	0.88 to 0.94	-0.43 to -0.56	-0.46 to -0.64
Fat yield		0.16 to 0.26	0.82 to 0.93	0.02 to 0.25	-0.36 to -0.12
Protein yield			0.18 to 0.28	-0.18 to -0.28	0.01 to -0.15
Fat (%)				0.10 to 0.61	0.41 to 0.85
Protein (%)					0.31 to 0.69

(Source: Park et al., 2017)

4.2. Dietary nutrients for improving milk production and composition

The synthesis of milk components is principally driven by secretory cells in the mammary gland from precursors derived directly or indirectly from circulating dietary nutrients (Pulina & Bencini, 2004). Therefore, the most effective approach to improve milk production and milk components is to alter dietary nutrition regimes (Bocquier & Caja, 2001; Kennelly et al., 2005). As most sheep milk is used for cheese making (Balthazar et al., 2017), with cheese yield depending mainly on milk fat and protein concentrations (Pellegrini et al., 1997), this review will emphasize the effect of dietary nutrients on the yields and contents of milk fat and protein.

4.2.1. Dietary nutrient composition and milk yield

Milk production by dairy ewes is mainly affected by voluntary feed intake or more accurately, the level of energy intake to support the high energy content of sheep milk (Park et al., 2017). Increasing the energy and nutritional value of the diet for lactating ewes is considered as one of the most critical strategies for improving milk production (Mikolayunas et al., 2008; Mikolayunas et al., 2011; Vazirigohar et al., 2014). Fat supplementation has been demonstrated as an effective tool for not only improving milk yield (Palmquist, 1994; Vazirigohar et al., 2014) but also for altering milk composition for human health benefits (Kennelly et al., 2005). Various types and dosages of oil supplemented with dairy ewes have resulted in significant variation in animal performance (Table 5).

Table 5. Effect of lipid supplementation on milk yield and composition of dairy ewes

Diet	MY	Fat	FY	Protein	PY	References
Palm oil	1242	8.43	103.8	5.18	64.0	Bodas et al. (2010)
Olive oil	1288	9.55	120.3	5.35	67.9	
Soybean oil	1321	8.37	111.9	5.23	68.2	
Linseed oil	974	8.77	96.5	5.29	55.2	
Control	3280	6.15	125.9	5.22	107.1	Toral et al. (2010)
Sunflower oil (SO)	3585	6.51	140.9	5.16	110.1	
SO + 8 g/ kg DM of Marine Algae	3608	5.75	115.7	4.93	98.7	
SO + 16 g/ kg DM of Marine Algae	3436	5.76	118.4	4.95	103.4	
SO + 24 g/ kg DM of Marine Algae	3459	5.29	101.7	4.96	95.5	
Control	1362	5.91	80.4	4.81	65.47	Mughetti et al. (2012)
100 g extruded linseed	1404	6.07	85.15	4.81	67.48	
200 g extruded linseed	1217	6.10	74.19	4.89	59.56	
Control	825	5.80	47.8	5.56	45.8	Buccioni et al. (2015)
Chestnut tannin	978	5.78	56.5	5.12	50.1	
Control	283.8	6.94	19.49	5.74	16.46	Caroprese et al. (2016)
Seaweed	324.2	7.21	22.96	5.85	19.09	
Whole flaxseed	341.5	6.84	22.75	5.88	19.81	
Seaweed + Whole flaxseed	346.3	6.85	22.36	5.89	19.48	
Control	484	7.4	36	5.4	26	Nguyen et al. (2018)
Canola oil	525	7.2	38	5.5	29	
Rice bran oil	527	7.2	38	5.9	31	
Flaxseed oil	489	6.9	34	5.4	26	
Safflower oil	562	6.6	37	5.6	31	
Rumen-protected oil	628	6.6	41	5.4	34	
Control	782	6.42	50	5.69	50	Antonacci et al. (2018)
Soybean oil (SO)	963	5.96	60	5.67	50	
Linseed oil (LO)	862	6.59	60	5.18	50	
75% SO + 25% LO	854	6.56	60	5.79	50	
50% SO+ 50% LO	805	6.75	60	6.10	50	
25% SO + 75% LO	902	7.09	60	6.10	50	

Milk yield (MY, g/day), fat (g/100 g milk), fat yield (FY, g/day), protein (g/100 g milk), protein yield (PY, g/day)

4.2.2. Dietary nutrient composition and milk protein content

Milk protein content is influenced by many nutritional factors with a lesser magnitude of changes than that of milk fat concentration in both dairy cows (Kennelly et al., 2005) and sheep (Pulina et al., 2006). According to Bocquier & Caja (2001), dietary energy concentration is positively correlated with milk protein content, especially when the energy sources are soluble carbohydrates (Gerson et al., 1985). This is because carbohydrates are energy sources of most rumen microbes including bacterial protein that control nitrogen utilization in the rumen (Russell et al., 1992). Similar to dairy cows (Huhtanen & Hristov, 2009), dietary crude protein (CP) content has a negative influence on milk protein percentage in dairy sheep (Bocquier & Caja, 2001). This can be explained as the CP content of the diet increases, it may exceed microbial needs which induce excessive urinary N (Broderick, 2003) together with a decrease in microbial protein synthesis (Broderick & Clayton, 1997).

In addition, results from Gonzalez et al., (1982) and Purroy & Jaime (1995) showed that milk protein content and yield can be influenced by different protein sources, probably due to the variation in rumen undegraded CP in dietary protein (Pulina et al., 2006). In response to lipid supplementation, inconsistent results in milk protein concentration have been reported (Table 5). The wide range of inclusion rates, dietary components, and feeding regimes may have led to these contrasting outcomes.

4.2.3. Dietary nutrients and milk fat content

Among the components of milk, fat content is the most amenable to change by altering dietary composition (Kennelly et al., 2005). Energy balance (EB), neutral detergent fiber (NDF) intake and source, as well as dietary fat supplements are the most important factors influencing both milk fat yield and concentration (Bocquier & Caja, 2001; Pulina et al., 2006).

Generally, milk fat content has a negative correlation with the level of nutrition in dairy cows (Palmquist et al., 1993) and sheep (Caja & Bocquier, 2000). Undernutrition is often observed in typical extensive or semi-intensive dairy ewe grazing systems, resulting in negative EB, and inducing an increase in milk fat concentration (Bocquier & Caja, 2001), probably due to lower milk volumes and/or high body fat mobilization into milk. Moreover, the relationship between fat content and EB is stronger for higher milk production ewes and becomes weaker for lower milk production ewes (Pulina et al., 2006).

A positive correlation between fat content and dietary NDF has been confirmed consistently in dairy cows, but inconsistently in dairy sheep (Pulina et al., 2006). Examining the relationship between NDF content and milk fat yield of 10 different dairy ewe breeds, Mele et al. (2005) observed the highest fat yield in milk from ewes fed diets that contained 35% NDF based on dry matter. These authors also noticed that when NDF level was either higher than 35% or lower than 30%, daily milk fat yield decreased. In contrast, Nudda et al. (2004) reported a weak positive correlation of +0.38 between dietary NDF and fat yield. However, Natel et al., (2013) found that an increase in the levels of dietary NDF did not affect the composition of milk, although it significantly decreased milk yield. Thus, the positive effect of NDF on milk fat content may be largely contributed by a strong negative association between milk yield and NDF (Pulina et al., 2006). Variable responses were also observed for milk fat content when different sources of fat were included in the diet of dairy sheep (Table 5).

4.3. Other factors affecting milk yield and composition

Besides genetics and nutrition, other factors including parity, lambing season, milking frequency, and stage of lactation also influence milk content and yield in ewes (Sevi et al., 2000; Bocquier & Caja, 2001; Abd Allah et al., 2011). According to Nudda et al. (2003) and Novotná et al. (2009), the highest daily milk yield is observed in parities 2 and 3. This high production normally remains up until the sixth lactation (6 years of age) (Pugliese et al., 1999) and then decreases. Differences in udder glandular tissue (Sevi et al., 2000) also significantly contribute to the changes in milk protein and fat contents between ewes in their first and second lactations (Novotná et al., 2009).

In terms of milking frequency, ewes milked twice a day tend to produce higher milk yield with a lower percentage of fat and protein than those milked once daily (Nudda et al., 2002). This is due to the autocrine regulation or local feedback mechanism of milk secretion which is defined as a self-regulated ability of the mammary gland largely without the impact of systemic hormones or signals (Wilde et al., 1998; Weaver and Hernandez, 2016) presented in sheep (Bencini et al., 2003). Positive local feedback that causes greater milk secretion, can be induced by several factors such as increasing milking frequency (Wall & McFadden, 2012), cell proliferation (Collier et al., 1993), cell differentiation (Lykos et al., 2000), serotonin and parathyroid hormone activity (Laporta et al., 2014), somatostatin (Bauman & Vernon, 1993), and prolactin (Chen et al., 2012). The completeness of milk removal could affect milk secretion through changes in mammary blood flow together with the number and activity of secretory cells (Wilde & Peaker, 1990; Wall & McFadden, 2012). In addition, responses to milking frequency changes were not consistent across different breeds, probably due to the difference in the udder storage capacity (Pulina et al., 2007).

The influences of lambing season and stage of lactation on lactation traits, on the other hand, are generally attributed to the nutrient value of available pastures in the grazing system (Cappio-Borlino et al., 1997). Day length (hours of light) in different lambing seasons also results in changes in milk production (Cannas & Pulina, 2002). Increasing daylight for a long period (more than 30 days) resulted in an increase in feed intake and consequently improves milk production, the reverse effect was observed with a short-term increment in day length (Pulina et al., 2007).

5. BODY CONDITION SCORE AS AN ESSENTIAL MANAGEMENT TOOL FOR DAIRY SHEEP PRODUCERS

Body condition score (BCS) has been employed as a health management tool for estimating body fat or energy reserves (Caldeira et al., 2007) as well as animal welfare status (Morgan-Davies et al., 2008; Caroprese et al., 2009; Phythian et al., 2011). BCS in dairy sheep was first standardized in the 1960s (Russel et al., 1969). The technique uses subjective palpation along the backbone and ribs to evaluate bone sharpness or muscle roundness with the score varying from 1 to 5. Ewes with BCS scores lower than 2 are identified as being thin and emaciated; an indication of sub-optimal nutrition during early lactation, while ewes with BCS 4 and above are considered obese and probably over-fed (Caroprese et al., 2009).

According to Cannas & Boe (2003), the body weight of any sheep breed can be predicted by BCS which may assist producers in terms of estimating the volume and quality of feed needed to meet the nutrient requirements of ewes. A comprehensive review by Kenyon et al. (2014) confirmed the positive association between BCS and ewe reproductive traits in different sheep breeds and suggested that the optimum ewe BCS at breeding is between 2.5 - 3.0 in order to have the highest pregnancy rate. Morgan-Davies et al. (2008) found an increased lamb survival rate in subsequent winters of ewes which had higher BCS scores in their mid-pregnancy. The relationship between BCS and milk production of dairy animals has been mostly determined for cows (Domecq et al., 1997; Berry et al., 2003; Jilek et al., 2008). Domecq et al. (1997) demonstrated that increasing one-point BCS of dairy cows during the dry period resulted in 545.5 kg more milk in the first 120 days of lactation period. Therefore, knowledge of BCS and its correlation with animal performance traits would help sheep producers to improve productivity through appropriate nutritional management of feed intake at different stages of production.

6. CONCLUSION

Sheep milk, in regard to its high content of fatty acids, proteins, vitamins, and minerals, is a crucial source of healthy bioactive substances for humans. The future development of the dairy sheep industry, therefore, is expected to thrive and be a new avenue for animal husbandry development. Breed and dietary nutrition have been the main factors that affect milk production, as well as milk fat concentration. Milk protein content, on the other hand, is more stable and harder to alter compared to milk fat concentration. Production and studies on dairy sheep remain scarce in many developing countries and thus further investigation needs to be undertaken to comprehensively understand the different production conditions of dairy ewes ultimately. Moreover, further research on genetics to uncover more genes and their functions in regulating milk production and quality also needs to be conducted in order to promote the popularity of healthy sheep milk in the human diet across the world.

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