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Fatty Acid Composition and Nutritional Indices/Ratios of Colostrum and Milk from Crossbred Goats in the Philippines

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ABSTRACT

Fatty acid (FA) profiles are important measures of the nutritional quality of goat's milk that may impact human cardiovascular health and disease. This study is aimed to compare the FA composition and FA-based nutritional indices/ratios of goat colostrum and milk from crossbred goats in relation to published reports on milk FAs involving purebred goats from other countries. A total of 121 colostrum and milk samples collected on the 30th, 60th, and 90th day of lactation from 33 crossbred goats with Anglo Nubian or Boer sires were analyzed by gas chromatography. The major FAs with the highest proportion in both colostrum and milk were oleic acid (C18:1-n9c), palmitic acid (C16:0), myristic acid (C14:0), and stearic acid (C18:0). Oleic acid, palmitic acid, and myristic acid were significantly higher ($p<0.05$) in colostrum than in milk (i.e., 27.4% vs 16.8%–22.9%, 24.8% vs 17.8%–19.6%, and 9.6% vs 5.2%–7.4%, respectively). Stearic acid was comparable in colostrum (8.8%) and milk (7.6%–10.8%). Total SFA and MUFA were higher in colostrum than in milk. Colostrum and milk contained low levels (less than 1.5%) of polyunsaturated fatty acids (PUFAs) – omega-6 FAs [i.e., linoleic acid C18:2 n-6 and arachidonic acid C20:4 n-6] and omega-3 FAs [i.e., α-linolenic acid C18:3 n-3 and docosahexaenoic acid C22:6 n-3]. The SFAs (C12:0, C14:0, C16:0, and C18:0) in relation to total MUFAs and PUFAs are known to contribute to the increase in cardiovascular disease. Thus, milk from crossbred goats seems to be more beneficial for cardiovascular health because of its lower atherogenicity and thrombogenicity and higher hypocholesterolemic/hypercholesterolemic ratio than those reported for several transboundary and local breeds.

Keywords: colostrum; crossbred goats; fatty acids; milk; nutritional indices

INTRODUCTION

The goat inventory in the Philippines in 2021 was about 3.95 million heads, mostly raised in smallholder/backyard farms for meat production (PSA, 2022). Goat milk is the third most-produced milk after cow's (bovine) milk and buffalo milk, contributing less than 2 percent of the 2019 dairy output of 24.4 million liters (PSA, 2020). Goat milk is commercially produced in semi-intensive farms, in which imported dairy breeds (Anglo Nubian, Boer, Saanen, Alpine, and Toggenburg) may be crossed with native goats to improve the latter's milk production. Despite the low level of goat milk production in these farms, there is growing interest in milk and dairy products from goats as more people become aware of the nutritional value of milk and its possible effect on cardiovascular health and disease (e.g., Faye & Konuspayeva, 2012; De Souza *et al.*, 2015; Hanus *et al.*, 2018).

The FA composition, as a measure of the quality of raw milk used in the production of milk and dairy products from goats, may vary depending on the breed (Martinez *et al.*, 2011; Curro *et al.*, 2019), dietary sources of fat (Ayeb *et al.*, 2015; Kholif *et al.*, 2016), nutrition and management (Haile *et al.*, 2016), stage of lactation (Curro *et al.*, 2019), production system (Lopez *et al.*, 2019), and season (Kasapidou *et al.*, 2022). Milk FAs have been reported for transboundary breeds (i.e., breeds found in more than one country) such as Alpine goats in Italy (Lopez *et al.*, 2019), Anglo Nubian in Egypt (Kholif *et al.*, 2016), and Saanen in China (Haile *et al.*, 2016), Estonia (Yurchenko *et al.*, 2018), and Italy (Curro *et al.*, 2019), and local breeds (i.e., breeds found in only one country) – including the indigenous goat breeds in Italy – Garganica, Girgentana, Jonica, Maltese, and Mediterranean Red (Curro *et al.*, 2019) and in Tunisia (Ayeb *et al.*, 2015), Malagueña goats in Spain (Martinez *et al.*, 2011), native goats in Greece (Kondyli *et al.*, 2012), Peranakan Etawah goats in Indonesia (Sumarmono & Sulistyowati, 2015), and Swedish Landrace goats in Estonia (Yurchenko *et al.*, 2018). On the other hand, studies on FAs in goat colostrum are uncommon.

Although FAs may play positive or negative roles in preventing and treating diseases (Chen & Liu, 2020), there is little information on a harmonized measurement of the nutritional quality of goat milk based on FA composition. To our knowledge, no similar study for colostrum and milk was obtained from crossbred goats – especially in the tropics. Hence, the FAs in colostrum and milk from crossbred goats are assumed to be similar to those reported for purebred goats from other countries.

In this regard, this study aimed to determine the FA composition and corresponding FA-based nutritional indices/ratios of goat colostrum and milk obtained on the 30th, 60th, and 90th day of lactation. These were compared for colostrum and milk samples collected from two-way and three-way crossbred goats with Anglo Nubian or Boer sire in an institutional dairy goat farm in the Philippines. The milk fat percentage, major FAs with the highest proportions, and FA-based nutritional indices/ratios were also compared with published reports on milk FAs involving purebred goats from other countries.

MATERIALS AND METHODS

Experimental Animals and Colostrum/Milk samples

A total of 121 milk samples were from thirty-three 2-way or 3-way crossbred does with Anglo Nubian (dairy-type) or Boer (meat-type) sires at the Small Ruminant Center institutional herd, Central Luzon State University, Muñoz, Nueva Ecija (Table 1). The two-way crosses were "Anglo Nubian × Native" and "Boer × Native", while three-way crosses were "Anglo Nubian × Boer × Native" and "Boer × Anglo Nubian/Alpine/ Saanen × Native". The average age at kidding was 4.27 ± 1.29 years, while the parity number was 2.63 ± 1.45.

Crossbred does were maintained in a complete confinement production system and provided with roughage, commercial feed concentrate (300 g/day/animal) and supplemented with vitamins and minerals all year round. The nutritional content of the feed concentrates in pellet form contained 6.0% crude fat, 16.1% crude protein, 11.3% crude fiber, 7.8% moisture, 8.8% ash, 1.12% calcium, and 0.58% phosphorus. Cultivated forages comprised of Napier (*Pennisetum purpureum*) and para grass (*Brachiaria mutica*) and leguminous species such as *Leucaena leucocephala*, *Gliricidia sepium*, *Centrosema pubescens*, *Desmodium cineria,* and *Indigofera zollingeriana* under a cut and carry system. The research protocol used in this study was approved by the Institutional Animal Care and Use Committee of the College of Veterinary Medicine, University of the Philippines Los Baños, Laguna, Philippines (approval number 2019-0034).

The colostrum (obtained within 24 hours after kidding) and raw milk samples that were taken on the 30th, 60th, and 90th day of lactation were collected by hand, placed in 250 mL plastic bottles, and immediately frozen at –20 °C until further analysis. The laboratory analysis of fat content and FA composition of colostrum and milk samples were performed at the Advanced Animal Science Training and Research Laboratory, Institute of Animal Science, College of Agriculture and Food Science, the University of the Philippines Los Baños.

Eight saturated fatty acids (SFAs), 6 monounsaturated fatty acids (MUFAs), and 4 polyunsaturated fatty acids (PUFAs) were analyzed as a percentage (g/100 g) of total FAs. The SFAs included lauric acid (C12:0), myristic acid (C14:0), pentadecylic acid (C15:0), palmitic acid (C16:0), margaric acid (C17:0), stearic acid (C18:0), arachidic acid (C20:0), and behenic acid (C22:0). The MUFAs were myristoleic acid (C14:1 n-5), palmitoleic acid (C16:1 n-7), oleic acid (C18:1 n-9), C18:1 n-7), eicosenoic acid (C20:1 n-11), and erucic acid (C22:1 n-9). The PUFAs comprised of linoleic acid or LA (C18:2 n-6), α-linolenic acid or ALA (C18:3 n-3), arachidonic acid or AA (C20:4 n-6), and docosahexaenoic acid or DHA (C22:6 n-3).

Six FA groups were determined, including total SFA, MUFA, PUFA, unsaturated fatty acids or UFA (i.e., MUFA + PUFA), omega-3 FA (i.e., C18:3 n-3 + C22:6 n-3), and omega-6 FA (i.e., C18:2 n-6 + C20:4 n-6). In addition, eight FA-based nutritional indices/ratios with health implications (Chen & Liu, 2020) were calculated, including PUFA to SFA ratio, MUFA to SFA ratio, n-6 to n-3 ratio, LA to ALA ratio, atherogenicity index (IA) and thrombogenicity index (IT) according to Ulbricht & Southgate (1991), health-promoting index (HPI) by Chen *et al*. (2004), and hypocholesterolemic/hypercholesterolemic (h/H) ratio by Mierlita (2018).

Table 1. Number and distribution of samples from crossbred does, by milk type, crossbreed combination, and breed of sire

Crossbred goats	Milk types					
	Colostrum	30-d Milk	60-d Milk	90-d Milk	Total samples	Total animals
Two-way crosses*						
With Anglo Nubian sire	15	17	16	15	63	17
With Boer sire	3	5	5	5	18	5
Total 2-way crosses	18	22	21	20	81	22
Three-way crosses**						
With Anglo Nubian sire	4	4	4	4	16	4
With Boer sire	4	7	7	6	24	7
Total 3-way crosses	8	11	11	10	40	11
Total samples	26	33	32	30	121	33

Note: *Two-way crosses include "Anglo Nubian × Native" and "Boer × Native"; **Three-way crosses include "Anglo Nubian × Boer × Native" and "Boer × Anglo Nubian/Alpine/ Saanen × Native".

The equations for IA, IT, HPI, and h/H ratio were as follows:

IA = [C12:0 + (4 × C14:0) + C16:0] / ΣUFA

IT = (C14:0 + C16:0 + C18:0) / [(0.5 × MUFA) + (0.5 × n-6 PUFA) + (3 × n-3) + (n-3 / n-6)]

HPI = UFA / [C12:0 + (4 × C14:0) + C16:0]

h/H ratio = (C18:1 n-9 + PUFA) / (C12:0 + C14:0 + C16:0)

Analysis of Fat Content

The fat content of colostrum and milk samples was analyzed using the MilkoScan Mars (FOSS Analytical A/S, Hillerod, Denmark) which is based on Fourier-transformed infrared spectroscopy technology.

Fat Extraction and Analysis of FA Profile

The extraction of fat from colostrum and milk samples and the preparation of fatty acid methyl esters (FAMEs) were done following the methods used by Bondoc & Ramos (2022) for buffalo colostrum and milk. About 3 mL of 8% methanolic HCl solution, 1 mL of n-hexane, and 3 mL of distilled water were added to the samples in a screw-capped glass test tube and centrifuged for 5 min at 8000 rpm. The upper organic hexane layer was transferred into 2 mL amber gas chromatography (GC) vials and purged with ultra-pure nitrogen gas for 20 s before storage in the refrigerator (–20 °C).

The FAs were separated and quantified using a Shimadzu GC 2010 Plus capillary GC system (Shimadzu Corporation, Kyoto, Japan) that is equipped with a flame ionization detector (FID) and AOC-20i autosampler. An aliquot µL of the hexane phase was injected in split mode (50:1) onto a FAMEWax (USP G16) capillary column (30 m, 0.32 mm ID, and 0.25 µm film thickness, Restek Corporation, U.S.). The injector port and FID temperatures were set to 125 °C, then increased to 240 °C at 3 °C min^{-1} and maintained for 5 min. Hydrogen was used as a carrier gas at 40 mL min^{-1}, while nitrogen was used as a makeup gas at 30 mL min^{-1}. The FAMEs were identified using the LabSolutions software by comparing the retention times of sample peaks with known FAME standards obtained from Sigma Aldrich.

The FA composition of the feed concentrates for lactating does was also analyzed to contain 64.32% SFA [i.e., C12:0 (37.64%), C14:0 (13.60%), C16:0 (10.02%), C18:0 (2.48%), C20:0 (0.50%), and C22:0 (0.08%)], 14.24% MUFA [i.e., 16:1 n-7 (0.07%) and C18:1n9c (14.17%)], and 8.12% PUFA [i.e., C18:2 n-6 (8.00%) and C18:3 n-3 (0.12%)].

Statistical Analysis

Differences in fat content among the milk types and between two-way and three-way cross with Anglo Nubian or Boer sires were determined using ANOVA. Individual FAs were analyzed using general least squares procedures for unbalanced data. Statistical significance was set at p-value <0.05. The mathematical model was: $y_{ijklmn} = \mu + MType_i + (MType_i \times BrComb_j \times SireBr_k) + Age_l + Fat_m + e_{ijklmn}$ where y_{ijklmn} is the proportion of FA (g/100 g of total FAs), µ is the overall mean, $MType_i$ is the effect of the i^{th} type of milk (i.e., colostrum and milk collected on the 30^{th}, 60^{th}, and 90^{th} day of lactation), $MType_i \times BrComb_j \times SireBr_k$ is the interaction effect among the i^{th} milk type, j^{th} crossbreed combination (two-way and three-way crosses), and k^{th} breed of sire (i.e., Anglo Nubian and Boer), Age_l is the l^{th} covariate effect of age at kidding (years), Fat_m is the m^{th} covariate effect of fat percentage, and e_{ijklmn} is the error term.-

The least-square means for each FA were used to calculate PUFA/SFA ratio, MUFA/SFA ratio, LA/ALA ratio, n-6/n-3 ratio, atherogenicity index (IA), thrombogenicity index (IT), health-promoting index (HPI), and hypocholesterolemic/hypercholesterolemic ratio (h/H). The nutritional indices/ratios were then compared between milk types, between crossbreed combinations and sire breeds for each type of milk. Regression coefficients (no intercept model) were determined for FAs and found to be significantly associated with age at kidding and fat content.

RESULTS

Factors Affecting Fat Percentage and FA Composition

Among the major SFAs with the highest proportions, C18:0 was the most variable, with a coefficient variation (CV) of 38.40% – followed by C14:0 (CV= 37.68%), and C16:0 (CV= 21.82%). The CV for important UFAs, i.e., C18:1 n-9, C18:2 n-6, C18:3 n-3, C20:4 n-6, and C22:6 n-3, was 27.86%, 30.01%, 45.59%, 57.39%, and 74.48%, respectively (Table 2).

Fat percentage in colostrum and milk was affected by the type of milk and age at kidding (Table 2). Fat percentage was significantly higher (p<0.05) in colostrum (4.75%) than in milk collected on the 30^{th}, 60^{th}, and 90^{th} day of lactation (2.01%–2.71%), see Table 3. Older age at kidding was significantly associated (p<0.01) with a decrease in fat percentage.

The FA composition was affected by the type of milk, age at kidding, and fat percentage (Table 2). The SFAs – C14:0, C16:0, and C17:0 and the MUFAs – C16:1 n-7 and C18:1 n-9 were significantly higher (p<0.05) in colostrum than in milk collected on the 30^{th}, 60^{th}, and 90^{th} day of lactation, see Table 3. On the other hand, C15:0 and C22:0 – both SFAs was significantly lower (p<0.05) in colostrum than in milk. The proportion of other SFAs (C12:0, C18:0, and C20:0), MUFAs (C14:1 n-5, C18:1 n-7, C20:1 n-11, and C22:1 n-9), and PUFAs (C18:2 n-6 or LA, C18:3 n-3 or ALA, C20:4 n-6, AA, and C22:6 n-3 or DHA) were not significantly different between colostrum and milk. Older age at kidding was significantly associated (p<0.01) with a decrease in the proportion of C14:0. The higher fat percentage was associated with an increase in the proportion of C18:0 and C18:1 n-9 (p<0.01), but lower C12:0, C14:0, C16:0, and C14:1 n-5 (p<0.05).

Major FAs in Colostrum from Crossbred Goats

The four major FAs in colostrum from crossbred goats – representing about 70% of total FAs – were

Table 2. Mean square F tests for the effects of milk type, interaction effects among milk type, crossbreed combination, and sire breed, and covariate effects of age at kidding and fat content on the proportion of fatty acids in crossbred goats

	Milk type	Milk type × Crossbreed combination × Sire breed	Age at kidding (years)	Fat content (%)	CV (%)
SFA					
C12:0	**	ns	ns	* -0.211 ± 0.086	58.95
C14:0	**	*	* 0.439 ± 0.215	* -0.314 ± 0.120	37.68
C15:0	**	*	ns	* -0.014 ± 0.007	21.26
C16:0	**	ns	ns	ns	21.82
C17:0	**	ns	ns	ns	26.83
C18:0	**	ns	ns	** 0.485 ± 0.175	38.40
C20:0	**	ns	ns	ns	44.57
C22:0	**	ns	ns	ns	42.62
MUFA					
C14:1 n-5	**	ns	ns	* -0.010 ± 0.004	42.81
C16:1 n-7	**	*	ns	ns	22.06
C18:1 n-9	**	ns	ns	** 0.892 ± 0.289	27.86
C18:1 n-7	**	ns	ns	ns	52.18
C20:1 n-11	**	ns	ns	ns	38.16
C22:1 n-9	**	ns	ns	ns	63.18
PUFA					
C18:2 n-6	**	ns	ns	ns	30.01
C18:3 n-3	**	ns	ns	ns	45.59
C20:4 n-6	**	ns	ns	* -0.014 ± 0.007	57.39
C22:6 n-3	ns	ns	ns	ns	74.48

Note: [ns] no significant differences (p>0.05); [*] significant differences (p<0.05); [**] highly significant differences (p<0.01); Numbers in the covariate column are the regression coefficients and corresponding standard errors.

C18:1 n-9 (27.4%), C16:0 (24.8%), C14:0 (9.6%), and C18:0 (8.8%). These were followed by C12:0 with a lower proportion of 3.32% (see Table 3). Colostrum contained low levels of omega-6 FAs (i.e., LA and AA at 1.47% and 1.09%, respectively), and omega-3 FAs (i.e., ALA and DHA at 0.11% and 0.30%, respectively).

Major FAs in Milk from Crossbred Goats

The major FAs in goat's milk – representing about 47% to 61% of total FAs, consisted of C18:1 n-9 (16.8%–22.9%), C16:0 (17.8%–19.6%), C18:0 (7.6%–10.8%), and C14:0 (5.2%–7.4%) (see Table 3). Unlike C16:0, which was not significantly different for milk obtained on the 30th, 60th, and 90th day of lactation, C18:1 n-9 in milk collected on the 30th day of lactation (22.9%) was higher than on the 60th day (19.6%) and 90th day (16.8%) of lactation. C18:0 on the 30th day (10.8%) was also higher than on the 90th day (7.6%). In contrast, C14:0 on the 30th day and 60th day (5.4% and 5.2%) was lower than on the 90th day (7.4%). Milk contained small amounts of C12:0 at 2.06%–4.47%. Milk from crossbred goats contained low levels of omega-6 FAs, i.e., LA (1.14%–1.49%) and AA (0.18%–0.29%), and omega-3 FAs, i.e., ALA (0.12%–0.15%) and DHA (0.19%–0.29%).

The conjugated linoleic acid or CLA (C18:2 c9tll), which is widely recognized as an anticarcinogenic, antiatherogenic, anti-inflammatory, and weight-reducing substance found in dairy fat (Rodriguez-Alcala *et al.*, 2013; Cichosz *et al.*, 2020), was not detected in both colostrum and milk from crossbred goats.

FA Groups in Colostrum and Milk from Crossbred Goats

Total SFA was higher in colostrum than in milk (Table 3). The difference in total SFA was due to higher levels of palmitic and myristic acid in colostrum. The total unsaturated fatty acids (UFAs) were also higher in colostrum than in milk. This was largely because of higher total MUFA in colostrum than in milk. The difference in total MUFA was due to the lower levels of oleic acid in colostrum, while total PUFA was low in both colostrum and milk.

DISCUSSION

Comparison of Nutritional Indices/Ratios between Milk Types in Crossbred Goats

PUFA/SFA ratio. The PUFA/SFA ratio is an index commonly used to evaluate the impact of diet on cardiovascular health (Chen & Liu, 2020). All PUFAs in the human diet is known to reduce low-density lipoprotein cholesterol and depress the levels of serum cholesterol, whereas all SFAs add to high levels of serum cholesterol. A high PUFA/SFA ratio implies a positive impact of diet in protecting the cardiovascular system from the unhealthy effects of atherosclerotic lesions (Naeini *et al.*, 2020). In this study, the PUFA/SFA ratio was very low for both colostrum (0.04: 1) and milk (0.04-0.06: 1). The PUFA/SFA ratio was highest in 30-d Milk from 2 way-crosses with Anglo Nubian sire (0.07: 1) and lowest in 90-d Milk from 2-way crosses with Boer sire (0.03: 1), see

Table 3. Least-square means of fat percentage, proportion of fatty acid (g/100 g of total FAs), FA groups, and FA-based nutritional indices/ratios for colostrum and milk collected on the 30th, 60th, and 90th day of lactation of crossbred goats

Fatty acids	Milk types			
	Colostrum	30-d Milk	60-d Milk	90-d Milk
Fat percentage	4.75 ± 0.60[a]	2.01 ± 0.49[b]	2.31 ± 0.50[b]	2.71 ± 0.50[b]
Saturated FAs				
C12:0	3.32 ± 0.48[b]	2.06 ± 0.39[c]	2.82 ± 0.40[bc]	4.47 ± 0.39[a]
C14:0	9.64 ± 0.68[a]	5.42 ± 0.55[c]	5.24 ± 0.55[c]	7.41 ± 0.55[b]
C15:0	0.54 ± 0.04[c]	0.67 ± 0.03[b]	0.79 ± 0.03[a]	0.70 ± 0.03[b]
C16:0	24.83 ± 1.16[a]	19.65 ± 0.94[b]	17.75 ± 0.95[b]	17.82 ± 0.94[b]
C17:0	0.68 ± 0.04[a]	0.55 ± 0.03[b]	0.48 ± 0.03[bc]	0.44 ± 0.03[c]
C18:0	8.77 ± 0.99[bc]	10.85 ± 0.80[a]	9.93 ± 0.81[ab]	7.56 ± 0.80[c]
C20:0	0.19 ± 0.04	0.24 ± 0.02	0.18 ± 0.05	0.23 ± 0.04
C22:0	0.16 ± 0.02[b]	0.21 ± 0.02[a]	0.20 ± 0.02[a]	0.23 ± 0.02[a]
Monounsaturated FAs				
C14:1 n-5	0.21 ± 0.03[ab]	0.16 ± 0.02[b]	0.20 ± 0.02[b]	0.26 ± 0.02[a]
C16:1 n-7	1.29 ± 0.07[a]	1.16 ± 0.05[b]	1.02 ± 0.06[c]	1.13 ± 0.05[bc]
C18:1 n-9	27.43 ± 1.63[a]	22.86 ± 1.32[b]	19.60 ± 1.33[c]	16.78 ± 1.32[d]
C18:1 n-7	0.74 ± 0.13	0.97 ± 0.10	0.87 ± 0.10	0.94 ± 0.10
C20:1 n-11	0.31 ± 0.03	0.34 ± 0.03	0.35 ± 0.03	0.32 ± 0.03
C22:1 n-9	0.07 ± 0.03[b]	0.14 ± 0.02[a]	0.16 ± 0.03[a]	0.14 ± 0.04[ab]
Polyunsaturated FAs				
C18:2 n-6, LA	1.47 ± 0.11[a]	1.49 ± 0.09[a]	1.15 ± 0.09[b]	1.14 ± 0.09[b]
C18:3 n-3, ALA	0.11 ± 0.02	0.12 ± 0.01	0.15 ± 0.02	0.12 ± 0.02
C20:4 n-6, AA	0.19 ± 0.04[b]	0.29 ± 0.03[a]	0.18 ± 0.05[b]	0.23 ± 0.04[ab]
C22:6 n-3, DHA	0.30 ± 0.08	0.29 ± 0.07	0.19 ± 0.07	0.19 ± 0.06
SFA	48.18	39.64	37.41	38.88
UFA	32.12	27.82	23.88	21.25
MUFA	30.05	25.63	22.21	19.57
PUFA	2.07	2.19	1.67	1.68
n-3 (ALA + DHA)	0.41	0.41	0.34	0.31
n-6 (LA + AA)	1.66	1.79	1.33	1.37
PUFA/SFA ratio	0.04	0.06	0.04	0.04
MUFA/SFA ratio	0.62	0.65	0.59	0.50
LA/ALA ratio	13.16	12.64	7.90	9.28
n-6/n-3 ratio	4.07	4.40	3.98	4.38
Atherogenicity index	2.08	1.56	1.74	2.44
Thrombogenicity index	2.50	2.37	2.53	2.82
Health-promoting index	0.48	0.64	0.58	0.41
h/H ratio	0.78	0.92	0.82	0.62

Note: Means for FAs in the same row with different superscripts differ significantly ($p<0.05$).
[SFA] saturated fatty acids; [UFA] unsaturated fatty acids; [MUFA] monounsaturated fatty acids; [PUFA] polyunsaturated fatty acids; [LA] linoleic acid (C18:2 n-6); [ALA] α-linolenic acid (C18:3 n-3); [AA] arachidonic acid (C20:4 n-6); [DHA] docosahexaenoic acid (C22:6 n-3); [n-3] omega-3 fatty acids; [n-6] omega-6 fatty acids, [h/H ratio] hypocholesterolemic/hypercholesterolemic ratio

Table 4. The low amounts of PUFAs in relation to SFAs, suggest that healthier dairy products derived from colostrum or milk of crossbred goats will need supplementation with PUFAs.

MUFA/SFA ratio. The MUFAs are known to increase the activity of low-density lipoprotein receptors and decrease the cholesterol concentration in serum. A high MUFA/SFA ratio can thus have beneficial effects on human health (Chen & Liu, 2020). In this study, the MUFA/SFA ratio was comparable in colostrum (0.62: 1) and milk (0.50–0.65: 1). The MUFA/SFA ratio was highest in colostrum from 3 way-crosses with Anglo Nubian sire (0.73: 1) and lowest in 90-d Milk from 2-way crosses with Boer sire (0.44: 1), see Table 4.

LA/ALA ratio. The linoleic acid to α-linolenic acid (LA/ALA) ratio measures the balance between LA and ALA, which cannot be synthesized by humans. It was developed as a guide to improving the nutritional value of baby food or infant formula (milk), with a minimum reference value usually set within 5–15: 1 (Chen & Liu, 2020). A high LA/ALA ratio implies faster ALA synthesis rates, which are not present in baby food and infant formula. However, the LA/ALA ratio in the diet has no significant importance on adults since the tissues of

Table 4. Fatty acid-based nutritional indices/ratios of colostrum and milk from crossbred goats

Crossbred goats	Fatty acids-based nutritional indices/ratios							
	PUFA/ SFA ratio	MUFA/ SFA ratio	LA/ALA ratio	n-6/n-3 ratio	Athero-genicity index (IA)	Thrombo-genicity index (IT)	Health-promoting index (HPI)	h/H ratio
Colostrum								
2-way cross, Anglo Nubian sire	0.04	0.61	12.70	6.14	2.21	2.60	0.45	0.75
2-way cross, Boer sire	0.04	0.66	13.26	3.22	1.86	2.41	0.54	0.85
3-way cross, Anglo Nubian sire	0.04	0.73	11.95	5.51	1.65	2.29	0.61	0.95
3-way cross, Boer sire	0.05	0.50	14.91	2.96	2.77	2.74	0.36	0.60
30-d Milk								
2-way cross, Anglo Nubian sire	0.07	0.71	11.57	2.93	1.23	2.06	0.81	1.09
2-way cross, Boer sire	0.05	0.58	16.74	4.83	1.83	2.55	0.55	0.78
3-way cross, Anglo Nubian sire	0.05	0.70	16.90	6.55	1.71	2.30	0.59	0.93
3-way cross, Boer sire	0.05	0.59	8.97	5.06	1.45	2.63	0.69	0.91
60-d Milk								
2-way cross, Anglo Nubian sire	0.05	0.57	12.94	5.32	1.85	2.60	0.54	0.79
2-way cross, Boer sire	0.04	0.63	5.71	3.13	1.72	2.41	0.58	0.83
3-way cross, Anglo Nubian sire	0.05	0.62	13.63	4.84	1.69	2.49	0.59	0.88
3-way cross, Boer sire	0.04	0.56	7.49	3.80	1.96	2.68	0.51	0.74
90-d Milk								
2-way cross, Anglo Nubian sire	0.05	0.57	9.73	5.13	1.89	2.59	0.53	0.77
2-way cross, Boer sire	0.03	0.44	11.02	6.18	3.17	3.31	0.32	0.49
3-way cross, Anglo Nubian sire	0.05	0.55	7.44	3.83	2.09	2.60	0.48	0.69
3-way cross, Boer sire	0.05	0.46	8.55	3.33	2.76	2.84	0.36	0.59

Note: [SFA] saturated fatty acids; [UFA] unsaturated fatty acids; [MUFA] monounsaturated fatty acids; [PUFA], polyunsaturated fatty acids; [LA] linoleic acid; [ALA], α-linolenic acid; [AA] arachidonic acid; [DHA] docosahexaenoic acid; [n-3] omega-3 fatty acids; [n-6] omega-6 fatty acids; [h/H ratio] hypocholesterolemic/ hypercholesterolemic ratio.

adults have a lower rate of synthesis of α-linolenic acid than those of infants. In this study, LA/ALA ratio was higher in colostrum (13.16: 1) than in milk (7.90–12.64: 1). The LA/ALA ratio was highest in 30-d Milk from 3 way-crosses with Anglo Nubian sire (16.90: 1) and lowest in 90-d Milk from 2-way crosses with Boer sire (5.71: 1), see Table 4. Based on the prescribed reference values LA/ALA ratio, goat milk may be used for infants, especially from crossbred goats with Anglo Nubian sire.

n-6/n-3 ratio. The n-6/n-3 ratio measures the dietary contribution of omega-6 FAs (i.e., LA and AA) that are generally pro-inflammatory, in relation to omega-3 FAs (i.e., ALA and DHA) that are anti-inflammatory. A low n-6/n-3 ratio (1–2: 1) implies a favorable effect to alleviate the effects of inflammatory diseases and reduce the risk of many chronic diseases such as nonalcoholic fatty liver disease, cardiovascular disease, obesity, inflammatory bowel disease, rheumatoid arthritis, and Alzheimer's disease (Patterson *et al.*, 2012). In this study, the n-6/n-3 ratio was comparable for colostrum (4.07: 1) and milk (3.98–4.40: 1). For colostrum, the n-6/n-3 ratio was lowest in 3 way-crosses with Boer sire (2.96: 1). For milk, the n-6/n-3 ratio was lowest in 30-d Milk from 2 way-crosses with Anglo Nubian sire (2.93: 1), see Table 4.

Atherogenicity index. The index of atherogenicity (IA) is a measure of the dietary contribution of some SFAs (i.e., lauric acid, myristic acid, and palmitic acid, except stearic acid) that are pro-atherogenic, in relation to all MUFAs and PUFAs that are anti-atherogenic (Ulbricht & Southgate, 1991). The pro-atherogenic FAs favor the adhesion of lipids to cells of the circulatory and immunological systems, while anti-atherogenic FAs inhibit the accumulation of fatty plaque and reduce the levels of phospholipids, cholesterol, and esterified FAs. The low IA values in dietary fat suggest greater health benefits, i.e., a lower tendency to form fatty plaques in the arteries (Chen & Liu, 2020). In this study, the IA was comparable in colostrum (2.04) and milk (1.56–2.44). For colostrum, the atherogenicity was lowest in 3 way-crosses with Anglo Nubian sire (1.65); meanwhile, for milk, the IA value was lowest in 30-d Milk from 2 way-crosses with Anglo Nubian sire (1.23), see Table 4.

Thrombogenicity index. The index of thrombogenicity (IT) measures the dietary contribution of prothrombogenic SFAs (i.e., lauric acid, myristic acid, and palmitic acid) in relation to the anti-thrombogenic MUFAs and PUFAs (Ulbricht & Southgate, 1991). The low IT values in dietary fat suggest greater benefits for cardiovascular health, i.e., a lower tendency to form clots in blood vessels (Chen & Liu, 2020). In this study, the IT was comparable in colostrum (2.50) and milk (2.37–2.82). For colostrum, the thrombogenicity was lowest in 3 way-crosses with Anglo Nubian sire (2.29); meanwhile, for milk, the IT value was lowest in 30-d Milk from 2 way-crosses with Anglo Nubian sire (2.06), see Table 4.

Health-promoting index. The health-promoting index (HPI) is the inverse of the atherogenicity index (Chen *et al.,* 2004). A high HPI value suggests more benefits for human health. In dairy products such as milk and cheese, the HPI values range from 0.16–0.68 (Chen & Liu, 2020). In this study, the HPI was comparable in colostrum (0.48) and milk (0.41–0.58). For colostrum, the HPI was highest in 3 way-crosses with Anglo Nubian sire (0.61). For milk, the HPI value was highest in 30-d Milk from 2 way-crosses with Anglo Nubian sire (0.81), see Table 4.

h/H ratio. The hypocholesterolemic/hypercholesterolemic (h/H) ratio is a measure of the effect of dietary FA composition on cholesterol (Mierlita, 2018). It reflects the relationship between hypocholesterolemic FAs (oleic acid and PUFAs) and hypercholesterolemic FAs (lauric acid, myristic acid, and palmitic acid). A high h/H value suggests greater benefits for human health. The h/H ratio in dairy products ranges from 0.32–1.29: 1 (Chen & Liu, 2020). In this study, the h/H ratio was comparable in colostrum (0.78: 1) and milk (0.62 –0.92: 1). For colostrum, the h/H ratio was highest in 3 way-crosses with Anglo Nubian sire (0.95: 1). For milk, the h/H ratio was highest in 30-d Milk from 2 way-crosses with Anglo Nubian sire (1.09: 1) see Table 4. It is also suggested that using 90-d Milk from 2 way-crosses with Boer sires may result in higher blood cholesterol levels.

While goat colostrum may provide medical and nutritional benefits to human cardiovascular health in terms of higher MUFA and PUFA, the production of colostrum all year round in commercial quantities will be limited as the amount of colostrum produced by a dairy animal is less than one percent of its annual milk production (O'Callaghan *et al.,* 2020).

Fat Percentage, Major FAs, and Nutritional Indices/ Ratios of Milk from Crossbred Goats Compared with Milk from Other Breeds

Fat percentage. The fat content of milk from crossbred goats (2.0%–2.7%) was lower than those reported for transboundary breeds such as Alpine in Italy (Lopez *et al.,* 2019) and Saanen in China (Haile *et al.,* 2016) and Italy (Curro *et al.,* 2019). These were also lower than those reported for local breeds, such as native goats in Greece (Kondyli *et al.*, 2012), endangered goat breeds in Italy (Curro *et al.,* 2019), Malagueña goats in Spain (Martinez *et al.,* 2011), and indigenous goats in Tunisia (Ayeb *et al.,* 2015).

Major FAs. In general, milk fats from crossbred goats had a higher proportion of C18:1 n-9 but lower C14:0, C16:0, and C18:0 than those reported for milk from transboundary and local breeds. C18:1 n-9 in milk from crossbred goats was higher than those for Alpine goats in Italy (Lopez *et al.,* 2019), Anglo Nubian in Egypt (Kholif *et al.,* 2016), Saanen in Estonia (Yurchenko *et al.,* 2018) and Italy (Curro *et al.,* 2019), indigenous goats in Greece (Kondyli *et al.*, 2012), endangered goat breeds in Italy (Curro *et al.,* 2019), Swedish Landrace in Estonia (Yurchenko *et al.,* 2018), Malagueña goats in Spain (Martinez *et al.*, 2011), Peranakan Etawah goats in Indonesia (Sumarmono & Sulistyowati, 2015), and indigenous goats in Tunisia (Ayeb *et al.,* 2015).

C16:0 in milk from crossbred goats (17.8%–19.6%) was lower than those for Alpine goats in Italy (Lopez *et al.,* 2019), Anglo Nubian in Egypt (Kholif *et al.,* 2016), Saanen goats in China (Haile *et al.,* 2016), Estonia (Yurchenko *et al.,* 2018), and Italy (Curro *et al.,* 2019), indigenous goats in Greece (Kondyli *et al.*, 2012), endangered goat breeds in Italy (Curro *et al.,* 2019), Swedish Landrace in Estonia (Yurchenko *et al.,* 2018), Malagueña goats in Spain (Martinez *et al.,* 2011), and indigenous goats in Tunisia (Ayeb *et al.,* 2015). C16:0 in milk from crossbred goats, however, was higher than in milk from Peranakan Etawah goats in Indonesia (Sumarmono & Sulistyowati, 2015).

C18:0 in milk from crossbred goats (7.6%–10.8%) was also lower than that in the milk of Anglo Nubian in Egypt (Kholif *et al.,* 2016), Saanen goats in China (Haile *et al.,* 2016), Estonia (Yurchenko *et al.,* 2018), and Italy (Curro *et al.,* 2019), indigenous goats in Greece (Kondyli *et al.,* 2012), endangered goat breeds in Italy (Curro *et al.,* 2019), Swedish Landrace in Estonia (Yurchenko *et al.,* 2018), and Peranakan Etawah goats in Indonesia (Sumarmono & Sulistyowati, 2015). C18:0 in milk from crossbred goats, however, was higher than that in milk from Malagueña goats in Spain (Martinez *et al.,* 2011) and indigenous goats in Tunisia (Ayeb *et al.,* 2015).

C14:0 in milk from crossbred goats (5.2%–7.4%) was also lower than that in Alpine in Italy (Lopez *et al.,* 2019), Anglo Nubian in Egypt (Kholif *et al.,* 2016), indigenous goats in Greece (Kondyli *et al.*, 2012), endangered goat breeds in Italy (Curro *et al.,* 2019), Swedish Landrace in Estonia (Yurchenko *et al.,* 2018), Malagueña goats in Spain (Martinez *et al.,* 2011), and indigenous goats in Tunisia (Ayeb *et al.,* 2015). C14:0 in milk from crossbred goats, however, was higher than in milk from Peranakan Etawah goats in Indonesia (Sumarmono & Sulistyowati, 2015).

FA groups. In general, milk fats from crossbred goats had a lower proportion of total SFA, UFA, MUFA, PUFA, and omega-6 and omega-3 FAs than those reported for milk from transboundary breeds. Total UFA and MUFA in milk from crossbred goats were comparable with those from most local breeds. Total SFA in milk from crossbred goats (37.4%–39.6%) were lower than those reported for transboundary breeds – Alpine in Italy (Lopez *et al.,* 2019), Anglo Nubian in Egypt (Kholif *et al.,* 2016), Saanen in China (Haile *et al.,* 2016), Estonia (Yurchenko *et al.,* 2018), and in Italy (Curro *et al.,* 2019). These were also lower than those reported for a local breed, such as the endangered goat breeds in Italy (Curro *et al.,* 2019), Swedish Landrace in Estonia (Yurchenko *et al.,* 2018), Malagueña goats in Spain (Martinez *et al.,* 2011), and indigenous goats in Tunisia (Ayeb *et al.,* 2015). Total UFA in milk from crossbred goats (21.2%–27.8%) was lower than those reported for Anglo Nubian in Egypt (Kholif *et al.,* 2016), Saanen in China (Haile *et al.,* 2016) and Italy (Curro *et al.,* 2019), and endangered goat breeds in Italy (Curro *et al.,* 2019). Total UFA in milk from crossbred goats, however, was similar to those from Alpine in Italy (Lopez *et al.*, 2019) and Saanen and Swedish Landrace in Estonia (Yurchenko *et al.*, 2018), Malagueña goats in Spain (Martinez *et al.*, 2011), and indigenous goats in Tunisia (Ayeb *et al.*, 2015). Total MUFA in milk from crossbred goats (19.6%–25.6%) were similar to those reported for other transboundary breeds – Alpine in Italy (Lopez *et al.*, 2019), Saanen in Estonia (Yurchenko *et al.*, 2018) and Italy (Curro *et al.*, 2019), endangered goat breeds in Italy (Curro *et al.*, 2019), Swedish Landrace in Estonia (Yurchenko *et al.*, 2018), Malagueña goats in Spain (Martinez *et al.*, 2011), and indigenous goats in Tunisia (Ayeb *et al.*, 2015). However, the total MUFA in milk from crossbred goats was lower than those reported for Anglo Nubian in Egypt (Kholif *et al.*, 2016) and Saanen in China (Haile *et al.*, 2016). Total PUFA in milk from crossbred goats (1.7%-2.2%) were lower than those reported for Alpine in Italy (Lopez *et al.*, 2019) and Saanen in China (Haile *et al.*, 2016), Estonia (Yurchenko *et al.*, 2018), and Italy (Curro *et al.*, 2019), endangered goat breeds in Italy (Curro *et al.*, 2019), Swedish Landrace in Estonia (Yurchenko *et al.*, 2018), Malagueña goats in Spain (Martinez *et al.*, 2011), and indigenous goats in Tunisia (Ayeb *et al.*, 2015). Total PUFA in milk from crossbred goats, however, was higher than in Anglo Nubian in Egypt (Kholif *et al.*, 2016).

The omega-6 FAs in milk from crossbred goats (1.33%–1.79%) were lower than those reported for Alpine goats in Italy (Lopez *et al.*, 2019), Saanen goats in China (Haile *et al.*, 2016), Estonia (Yurchenko *et al.*, 2018), and Italy (Curro *et al.*, 2019), endangered breeds in Italy (Curro *et al.*, 2019), indigenous goats in Tunisia (Ayeb *et al.*, 2015), but higher than in Anglo Nubian in Egypt (Kholif *et al.*, 2016). The omega-3 FAs in milk from crossbred goats (0.31%–0.41%) were slightly lower than those reported for Alpine goats in Italy (Lopez *et al.*, 2019), Saanen goats in China (Haile *et al.*, 2016), Estonia (Yurchenko *et al.*, 2018), and Italy (Curro *et al.*, 2019), and endangered breeds in Italy (Curro *et al.*, 2019), but similar with Anglo Nubian in Egypt (Kholif *et al.*, 2016) and indigenous goats in Tunisia (Ayeb *et al.*, 2015).

PUFA/SFA ratio. The PUFA/SFA ratio in milk from crossbred goats (0.04-0.06: 1) was similar to those reported for Alpine in Italy (Lopez *et al.*, 2019), Saanen in China (Haile *et al.*, 2016) and Estonia (Yurchenko *et al.*, 2018), Swedish Landrace in Estonia (Yurchenko *et al.*, 2018), Malagueña goats in Spain (Martinez *et al.*, 2011), and indigenous goats in Tunisia (Ayeb *et al.*, 2015). This was, however, lower than in Saanen in Italy (Curro *et al.*, 2019) and endangered goat breeds in Italy (Curro *et al.*, 2019) but higher than in Anglo Nubian in Egypt (Kholif *et al.*, 2016).

MUFA/SFA ratio. The MUFA/SFA ratio in milk from crossbred goats (0.50–0.65: 1) was higher than those reported for Alpine in Italy (Lopez *et al.*, 2019), Anglo Nubian in Egypt (Kholif *et al.*, 2016), Saanen in Estonia (Yurchenko *et al.*, 2018), and Italy (Curro *et al.*, 2019), endangered goat breeds in Italy (Curro *et al.*, 2019), Swedish Landrace in Estonia (Yurchenko *et al.*, 2018), Malagueña goats in Spain (Martinez *et al.*, 2011), and indigenous goats in Tunisia (Ayeb *et al.*, 2015).

LA/ALA ratio. The LA/ALA ratio in milk from crossbred goats (7.90–12.64: 1) was similar to those in Saanen in China (Haile *et al.*, 2016) and Malagueña goats in Spain (9.86–11.82: 1). These were, however, higher than those reported for transboundary breeds – Alpine in Italy (Lopez *et al.*, 2019), Anglo Nubian in Egypt (Kholif *et al.*, 2016), Saanen in Estonia (Yurchenko *et al.*, 2018) and in Italy (Curro *et al.*, 2019), and local breeds – Peranakan Etawah goats in Indonesia (Sumarmono & Sulistyowati, 2015), endangered goat breeds in Italy (Curro *et al.*, 2019), indigenous goats in Tunisia (Ayeb *et al.*, 2015), and Swedish Landrace in Estonia (Yurchenko *et al.*, 2018).

n-6/n-3 ratio. The n-6/n-3 ratio in milk from crossbred goats (3.98–4.40: 1) was comparable with those in Alpine in Italy (Lopez *et al.*, 2019) but slightly lower than those reported for Saanen in China (Haile *et al.*, 2016), Estonia (Yurchenko *et al.*, 2018), and Italy (Curro *et al.*, 2019), endangered goat breeds in Italy (Curro *et al.*, 2019), Peranakan Etawah goats in Indonesia (Sumarmono & Sulistyowati, 2015), indigenous goats in Tunisia (Ayeb *et al.*, 2015), Swedish Landrace in Estonia (Yurchenko *et al.*, 2018), and Malagueña goats in Spain (Martinez *et al.*, 2011).

Atherogenicity index. The atherogenicity of milk from crossbred goats (1.56–2.44) was comparable with those from Saanen in China (Haile *et al.*, 2016) and Italy (Curro *et al.*, 2019) and endangered goat breeds in Italy (Curro *et al.*, 2019). These were, however, lower (i.e., better for cardiovascular health) than those reported for transboundary breeds – Alpine in Italy (Lopez *et al.*, 2019), Saanen in Estonia (Yurchenko *et al.*, 2018), and Anglo Nubian in Egypt (Kholif *et al.*, 2016), and local breeds – Swedish Landrace in Estonia (Yurchenko *et al.*, 2018), indigenous goats in Tunisia (Ayeb *et al.*, 2015), and Malagueña goats in Spain (Martinez *et al.*, 2011).

Thrombogenicity index. The thrombogenicity of milk from crossbred goats (2.37–2.82) was also comparable with those of Saanen in China (Haile *et al.*, 2016) and Italy (Curro *et al.*, 2019), and endangered goat breeds in Italy (Curro *et al.*, 2019). Milk from crossbred goats, however, had lower IT values (i.e., more beneficial for cardiovascular health) than those reported for transboundary breeds – Alpine in Italy (Lopez *et al.*, 2019), Anglo Nubian in Egypt (Kholif *et al.*, 2016), and Saanen in Estonia (Yurchenko *et al.*, 2018), and local breeds – Swedish Landrace in Estonia (Yurchenko *et al.*, 2018), indigenous goats in Tunisia (Ayeb *et al.*, 2015), Malagueña goats in Spain (Martinez *et al.*, 2011), and Peranakan Etawah goats in Indonesia (Sumarmono & Sulistyowati, 2015).

Health-promoting index. The HPI of milk from crossbred goats in this study (0.41–0.64) was comparable with Anglo Nubian in Egypt (Kholif *et al.*, 2016), Saanen in China (Haile *et al.*, 2016) and Italy (Curro *et al.*, 2019), endangered goat breeds in Italy (Curro *et al.*, 2019), and Peranakan Etawah goats in Indonesia (Sumarmono & Sulistyowati, 2015). The HPI values of milk from crossbred goats were, however, higher than those reported for transboundary breeds – Alpine in Italy (Lopez *et al.*, 2019) and Saanen in Estonia (Yurchenko *et al.*, 2018), and local breeds – Swedish Landrace in Estonia (Yurchenko *et al.*, 2018), indigenous goats in Tunisia (Ayeb *et al.*, 2015), and Malagueña goats in Spain (Martinez *et al.*, 2011).

h/H ratio. The h/H ratio of milk from crossbred goats was comparable with Saanen in Estonia (Yurchenko *et al.*, 2018) and Italy (Curro *et al.*, 2019), and Swedish Landrace in Estonia (Yurchenko *et al.*, 2018). The h/H ratio in milk from crossbred goats was higher than those from Alpine goats in Italy (Lopez *et al.*, 2019), Anglo Nubian in Egypt (Kholif *et al.*, 2016), indigenous goats in Tunisia (Ayeb *et al.*, 2015), and Malagueña goats in Spain (Martinez *et al.*, 2011). This was, however, lower than those of Saanen in China (Haile *et al.*, 2016), endangered goat breeds in Italy (Curro *et al.*, 2019), and Peranakan Etawah goats in Indonesia (Sumarmono & Sulistyowati, 2015).

Overall, the differences in fat percentage, major FAs, and nutritional indices/ratios of milk from crossbred goats compared to milk produced by various transboundary and local breeds in other countries may be attributed to differences in the feeding ration, dairy farming system, animal individuality, lactation order (parity), and lactation stage and their mutually combined effects (Hanus *et al.*, 2018). The comparisons, however, provide useful benchmark information for consumers and local dairy goat farms.

CONCLUSION

Colostrum obtained from crossbred goats has a higher fat percentage and proportion of major FAs than in milk. However, the FA-based nutritional indices/ ratios were comparable in colostrum and milk. Since the production of colostrum in commercial quantities will be limited, goat milk should be used instead to develop healthy dairy products and dietary food supplements. Milk from crossbred goats seems to be more beneficial for cardiovascular health because of its lower atherogenicity and thrombogenicity and higher h/H ratio than those reported from several transboundary and local breeds.

CONFLICT OF INTEREST

We certify that there is no conflict of interest with any financial, personal, or other relationships with other people or organizations related to the material discussed in the manuscript.

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