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Fatty Acid Profiles and Nutritional Indices/Ratios of Colostrum and Transient Milk from Landrace, Large White, and Landrace × Large White Crossbred Sows

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ABSTRACT

Fatty acid (FA) profiles are needed to assess the nutritional quality of sow colostrum and transient milk that may be used in developing milk replacer diets for piglets and their possible use as a functional food or nutraceutical. This study analyzed the FA profiles and compared the FA-based nutritional indices/ratios of colostrum and transient milk from Landrace, Large White, and Landrace × Large White crossbred sows in a swine nucleus breeding farm in the Philippines. Colostrum and transient milk samples were collected by hand within 24 h after parturition and 36–72 h after farrowing, respectively; immediately frozen at –20 °C until analyzed for FA composition by gas chromatography. Among the major FAs with the highest proportions, palmitic acid (C16:0) and linoleic acid LA (C18:2 n-6) were higher in colostrum (20.7% and 25.0%, respectively) than in transient milk (18.7% and 18.8%, respectively). Oleic acid (C18:1 n9c) was higher in transient milk (34.9%) than in colostrum (32.2%). The polyunsaturated FA (PUFA) to saturated FA (SFA) ratio was higher in sow colostrum (0.81:1) than transient milk (0.65:1). However, transient milk had better linoleic acid to α-linolenic acid C18:3 n-3 (LA/ALA) ratio, more balanced omega-6 to omega-3 (n-6/n-3) ratio, slightly lower atherogenicity index (IA= 0.43 vs 0.46) and thrombogenicity index (IT= 0.81 vs 0.85), higher health-promoting index (HPI= 2.33 vs 2.16), and higher hypocholesterolemic/ hypercholesterolemic ratio (h/H= 2.66:1 vs 2.55:1) than colostrum. Both colostrum and transient milk from Large White sows had lower IA and IT values and higher PUFA/SFA ratio, HPI, and h/H ratio compared to Landrace sows. Crossbred sows had colostrum and transient milk with lower average IT than purebred sows. The PUFA/SFA ratio, HPI, and h/H ratio in colostrum were also higher for crossbred sows than for purebred sows. In conclusion, colostrum from crossbred sows may be used in the preparation of milk replacer formulations for piglets, while transient milk, especially from Large White sows, may be considered in the development of sow milk -based supplements in the human diet.

***Keywords:** colostrum; fatty acids; nutritional indices; sow; transient milk*

INTRODUCTION

Colostrum intake, colostrum yield, and colostrum composition are important for the survival and good performance of the piglets (Declerck *et al.*, 2015). While lower in fat concentration than milk, colostrum fat is important for retaining fat, which helps insulate the piglet against additional heat loss, and for the oxidation of fat, which is important for thermoregulation (Quesnel *et al.*, 2012). However, piglets are born deficient in energy, and the development of hyper prolific pigs results in the decreased birth weight of piglets and increased competition between littermates. Therefore, new management systems are needed to improve colostrum yield and composition or increase transient milk production (Theil *et al.*, 2014). In this regard, the development of a proper colostrum "replacer" and sow milk substitutes to make up for the lack of sow milk for piglets of highly prolific sows was proposed by Inoue & Tsukuhara (2021) mainly to reduce piglet mortality. Ren *et al.* (2022) further suggested that fatty acid (FA) profiles of colostrum and milk fat could be used to optimize piglet formulas that would provide a suitable fat source to improve the energy supply for the survival and growth of piglets.

Compared to cow and sheep milk fat, the FA composition of sow colostrum was more similar to that of human colostrum and thus considered a new source of nutrients or functional food ingredient (Luise *et al.*, 2018) and nutraceutical (Ceniti *et al.*, 2022). However, unlike dairy cows which produce milk far beyond the amount required by the calf, the production of sow colostrum and milk in commercial quantities and their further processing into high value products will be limited by the milk intake requirement of the newborn piglets (about 250 g colostrum/piglet as recommended by Quesnel *et al.* (2012) and by the milk collection method with or without administration of oxytocin to stimulate milk ejection. Moreover, total colostrum yield from the sow can vary widely and is measured indirectly by summing up the colostrum ingested by all piglets in the litter, estimated by an equation that takes into account the birth weight and weight gain during the first 24 h of life (Machado *et al.,* 2016).

While the FA composition is reportedly affected by the breed of sow and parity (Luise *et al.,* 2018) and dietary sources of fat (Hurley, 2015), there is little information on the nutritional quality measurement of sow colostrum and milk that would signify the effect of FAs on human health and disease (Chen & Liu, 2020).

To explore their potential use in the manufacture of milk replacer diets for piglets and the assessment of their nutritional and/or medicinal values that may impact on human cardiovascular health, this study aimed to evaluate the fat content and FA profile and compare the FA-based nutritional indices/ratios of colostrum and transient milk samples collected from different sow breeds (*i.e.,* Landrace, Large White, and their F_1 crosses) in a swine nucleus breeding farm in the Philippines.

MATERIALS AND METHODS

Experimental Animals and Colostrum/Milk Samples

Ninety-four (94) milk samples (*i.e.,* 54 colostrum and 40 transient milk) were collected from 54 primiparous and multiparous sows consisting of Landrace (17), Large White (17), "F_1 Landrace × Large White" cross (13), and "R_1 Large White × Landrace" reciprocal cross (7) at the INFARMCO swine breeding farm in Barangay San Isidro, Cabuyao City, Laguna, Philippines (Table 1). The average age of the sows at farrowing was 2.37 ± 0.85 years, while the average number of parities in each sow was 4.06 ± 1.90. All sows were fed twice a day with a commercial lactation ration (*i.e.,* 4.0–6.0 kg/sow/day). The nutritional content of the lactation feed concentrates is comprised of 10.23% moisture, 15.21% crude protein, 4.91% crude fat, 5.00% crude fiber, 7.85% ash, and 2,440.0 kcal/kg net energy. This study was approved by the Institutional Animal Care and Use Committee of the University of the Philippines Los Baños, Laguna, Philippines (approval number 2019-00034).

Colostrum and transient milk samples were carefully collected by hand from functional teats within 24 h after parturition without the use of oxytocin and 36–72 h after farrowing, respectively. Approximately 40–50 mL of the colostrum and transient milk samples were placed in conical tubes and immediately frozen at –20 °C until further analysis.

A total of seven SFAs [*i.e.,* lauric acid (C12:0), myristic acid (C14:0), palmitic acid (C16:0), margaric acid (C17:0), stearic acid (C18:0), arachidic acid (C20:0), and behenic acid (C22:0)], six MUFAs [*i.e.,* myristoleic acid (C14:1 n-5), palmitoleic acid (C16:1 n-7), oleic (C18:1 n-9 acid), C18:1 n-7), eicosenoic acid (C20:1 n-11), and erucic acid (C22:1 n-9)], and five PUFAs [*i.e.,* conjugated linoleic acid or CLA (C18:2 c9tll), 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)] were analyzed as a percentage (g/ 100 g) of total FAs in the colostrum and milk samples.

Six FA groups were determined, namely, SFA, MUFA, PUFA, unsaturated fatty acids or UFA = MUFA + PUFA, omega-3 FA = C18:3 n-3 + C22:6 n-3, and omega-6 FA = C18:2 n-6 + C20:4 n-6). In addition, seven FA-based nutritional indices/ratios with health implications (Chen & Liu 2020) were calculated, including PUFA/SFA ratio, n-6/n-3 ratio, LA/ALA ratio, atherogenicity index (IA), thrombogenicity index (IT), health-promoting index (HPI), and hypocholesterolemic/hypercholesterolemic (h/H) ratio.

The IA and IT were calculated as IA = [C12:0 + (4 × C14:0) + C16:0] / ΣUFA, and IT = (C14:0 + C16:0 + C18:0) / [(0.5 × MUFA) + (0.5 × n-6 PUFA) + (3 × n-3) + (n-3 / n-6)] according to Ulbricht & Southgate (1991). Following Chen et al. (2004), the HPI = UFA / [C12:0 + (4 × C14:0) + C16:0]. The h/H ratio = (C18:1 n-9 + PUFA) / (C12:0 + C14:0 + C16:0), as used by Mierlita (2018).

The FA composition of the lactation ration were also analyzed to contain 37.83% total SFA [C12:0 (4.89%), C14:0 (3.91%), C16:0 (21.50%), C18:0 (5.77%), C20:0 (1.23%), and C22:0 (0.53%)], 20.62% total MUFA [C16:1 n-7 (0.34%) and C18:1n9c (20.28%)], and 25.47% total PUFA [C18:2 n-6 (25.14%) and C18:3 n-3 (0.33%)].

Analysis of Fat Content

The fat contents of sow colostrum and transient milk samples were 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 fat from sow colostrum and transient milk samples was extracted following the method presented by Folch *et al.* (1957) and used by Bondoc & Ramos (2022) for buffalo colostrum and milk. The fatty acid methyl esters (FAMEs) were prepared using the rapid methanolysis/ methylation procedure described by Ichihara & Fukubayashi (2010). 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 for the 19 medium- to very long-chained FAs (*i.e.*, grain FAME mix (CRM47801), AA (A3611), DHA (D2534), trans-vaccenic acid (V1131), and CLA (I6413)).

Statistical Analysis

The correlations among the individual FAs and their relationships with sow's age at farrowing, parity, and fat content were determined separately for sow colostrum and transient milk samples using the CORR procedure (SAS Ver. 9.2, 2009).

The general least squares procedures for unbalanced data were used to analyze each FA in colostrum and transient milk. Statistical significance was set at p value <0.05. The final mathematical model was as follows: $y_{ijklmn} = \mu + MType_i + Breed_j(MilkType_i) + Age_k + Parity_l + Fat_m + e_{ijklmn}$, where y_{ijklmn} is the proportion of FA (g/100 g of total identified FAs), μ is the overall mean, $MType_i$ is the fixed effect of the i^{th} type of milk (*i.e.*, colostrum and transient milk), $Breed_j$ ($MilkType_i$) is the fixed effect of the j^{th} breed of sow (*i.e.*, Landrace, Large White, "F_1 Landrace × Large White" cross, and "R_1 Large White × Landrace" cross) nested within the type of milk, Age_k is the covariate k^{th} effect of age at farrowing (years), $Parity_l$ is the l^{th} covariate effect of parity (number of farrowing), Fat_m is the m^{th} covariate effect of fat content, and e_{ijklmn} is the error term.

The least-square means for each FA were used to compute the nutritional indices/ratios and their differences between colostrum and transient milk and between breeds within the same type of milk. Regression coefficients (no intercept model) were also determined for FAs found to be significantly associated with age at farrowing, parity, and fat content.

RESULTS

Fat Content in Colostrum and Transient Milk

Fat content in sow colostrum (5.84% kg) was significantly lower (p<0.05) than in transient milk (6.95%) (Table 1). Fat content in colostrum and transient milk was the highest in F1 LDR × LRW crossbred sows (7.3% and 10.7%, respectively), but not significantly different (p>0.05) between Landrace (5.5% and 4.7%, respectively) and Large White sows (6.5% and 5.2%, respectively). Fat content in colostrum was slightly higher in purebred sows (6.0%) than in crossbred sows (5.7%). Fat content in transient milk was lower in purebred sows (4.7%) than in crossbred sows (9.0%). By comparison, Ren *et al.* (2022) reported lower fat content in colostrum of Landrace (5.1%), Large White (5.6%), and Landrace × Large White crosses (5.2%), but the higher fat content in milk of Landrace (7.5%), Large White (8.2%), and Landrace × Large White crosses (8.2%). A lower fat content in colostrum of Landrace (3.6%) and Large White (2.6%) was also reported by Luise *et al.* (2018).

Correlations Among Major Fatty Acids

In sow colostrum, oleic acid was significantly correlated with palmitic acid (r= 0.55) and linoleic acid (r= 0.56) (Table 2). Palmitic acid was significantly correlated with linoleic acid (r= 0.44). In the case of the major milk FAs, palmitic acid was significantly correlated with oleic acid (r= 0.37) and linoleic acid (r= 0.53). Percent oleic acid, however, was not related to linoleic acid (p>0.05).

Correlations of Major Fatty Acids with Age at Farrowing, Parity, and Fat Content

Palmitic acid (C16:0) in sow colostrum was negatively correlated with age at farrowing and parity (r= -0.31 and -0.32, respectively), but positively correlated with percent fat (r= 0.30) (Table 3). However, in transient milk, C16:0 was not correlated with age at farrowing, parity, and percent fat (p>0.05). Oleic acid (C18:1 n-9) was positively correlated with percent fat in both colostrum (r= 0.42) and transient milk (r= 0.54). Linoleic acid or LA (C18:2 n-6) in transient milk was significantly correlated with age at farrowing (r= 0.35).

Factors Affecting FA Composition

Among the major FAs with the highest proportion, linoleic acid was the most variable with a coefficient variation (CV) of 26.54%, followed by oleic acid (CV= 16.22%), and palmitic acid (CV= 16.18%) (Table 4).

Except for docosahexaenoic acid – DHA (C22:6 n-3), all FAs were significantly affected by the type of milk (p<0.01). Myristoleic acid (C14:1 n-5), erucic acid (C22:1 n-9), and conjugated linoleic acid or CLA (C18:2 c9t11) were detected only in a few (less than 10) colostrum/transient milk samples.

Table 1. Number of samples and least-square means for fat content in sow colostrum and transient milk from different breed types

Variables	Colostrum	Transient milk	Total
No. of samples			
Landrace	17	12	29
Large White	17	13	30
F1 LDR × LRW cross	13	8	21
R1 LRW × LDR cross	7	7	14
Total no. of samples	54	40	94
Fat content, %			
Landrace	5.46 ± 0.88^{b}	4.67 ± 0.89^{b}	
Large White	6.50 ± 0.74^{ab}	5.21 ± 0.93^{b}	
F1 LDR × LRW cross	7.28 ± 0.88^{a}	10.73 ± 1.11^{a}	
R1 LRW × LDR cross	4.11 ± 1.31^{b}	7.21 ± 1.19^{b}	
Overall LSM ± SE	5.84 ± 0.49^{y}	6.95 ± 0.52^{x}	

Note: Least-square means in the same column with different letter superscripts (a, b) are significantly different between sow breeds (p<0.05). Overall least-square means with different letter superscripts (x, y) are significantly different between sow colostrum and transient milk (p<0.05).
[F1 LDR × LRW] – crossbred sows with Landrace sire and Large White dam. [R1 LRW × LDR cross] – crossbred sows with Large White sire and Landrace dam.

Table 2. Pearson correlation coefficients among fatty acids in sow colostrum (upper right off-diagonals) and transient milk (lower left off-diagonals)

	Saturated fatty acid (SFA)							Monounsaturated fatty acid (MUFA)						Polyunsaturated fatty acid (PUFA)				
	C12:0	C14:0	C16:0	C17:0	C18:0	C20:0	C22:0	C14:1 n-5	C16:1 n-7	C18:1 n-9	C18:1 n-7	C20:1 n-11	C22:1 n-9	C18:2 c9t11	C18:2 n-6	C18:3 n-3	C20:4 n-6	C22:6 n-3
SFA																		
C12:0		**0.76**	ns	ns	ns	ns	ns	-	ns	ns	ns	ns	-	-	-0.4	ns	ns	ns
C14:0	0.67		**0.49**	0.4	ns	**0.77**	**-0.43**	-	0.33	ns	ns	ns	-	-	ns	**-0.41**	ns	ns
C16:0	ns	0.6		ns	0.35	ns	**-0.8**	-	ns	**0.55**	ns	-0.43	-	-	**0.44**	-0.33	ns	ns
C17:0	ns	**0.71**	ns		ns	**0.51**	ns	-	-0.47	-0.55	ns	ns	-	-	ns	ns	ns	ns
C18:0	-0.44	ns	0.37	ns		ns	-0.37	-	ns	**0.44**	0.34	ns	-	-	ns	ns	0.33	ns
C20:0	ns	**0.73**	ns	**0.8**	ns		-0.35	-	ns	ns	ns	ns	-	-	ns	-0.33	ns	ns
C22:0	ns	**-0.4**	**-0.78**	ns	-0.33	ns		-	**-0.45**	**-0.86**	-	**0.82**	-	-	**-0.66**	ns	ns	-
MUFA																		
C14:1 n-5	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-
C16:1 n-7	0.44	0.38	ns	**-0.58**	ns	ns	**0.51**	-		**0.48**	ns	ns	-	-	ns	ns	ns	ns
C18:1 n-9	ns	ns	0.37	-0.51	0.38	ns	**-0.76**	-	0.55		ns	-0.54	-	-	**0.56**	**0.44**	ns	ns
C18:1 n-7	ns	ns	**0.48**	**-0.62**	**0.51**	**-0.48**	**-0.71**	-	0.48	0.79		ns	-	-	-0.66	ns	ns	ns
C20:1 n-11	ns	ns	ns	ns	ns	ns	0.65	-	**-0.73**	ns	ns		-	-	-0.43	ns	ns	ns
C22:1 n-9	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	-	-
PUFA																		
C18:2 c9t11	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	-
C18:2 n-6	ns	**0.75**	**0.53**	**0.77**	ns	**0.9**	**-0.52**	-	ns	ns	ns	ns	-	-		ns	ns	ns
C18:3 n-3	ns	**-0.56**	ns	**-0.72**	ns	**-0.62**	-0.35	-	ns	**0.73**	**0.75**	ns	-	-	-0.44		ns	-
C20:4 n-6	ns	ns	ns	**0.56**	ns	ns	ns	-	ns	ns	ns	0.65	-	-	0.35	-0.41		-
C22:6 n-3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	

Note: [ns] correlation coefficient is not significantly different from zero, p>0.05. [Not in bold font] correlation coefficient is significantly different from zero, p<0.05. [In bold font] correlation coefficient is highly significantly different from zero, p<0.01. – [-] Number of paired observations is less than 10.

Table 3. Pearson correlation coefficients between individual fatty acids and age at farrowing, parity, and fat content in sow colostrum and transient milk

	Colostrum			Transient milk		
	Age at farrowing	Parity	Percent fat	Age at farrowing	Parity	Percent fat
SFA						
C12:0	ns	ns	Ns	ns	ns	ns
C14:0	ns	ns	ns	ns	ns	ns
C16:0	-0.31*	-0.32*	0.30*	ns	ns	ns
C17:0	ns	ns	ns	ns	ns	ns
C18:0	-0.27*	-0.28*	0.42**	-0.31*	-0.34*	ns
C20:0	ns	ns	ns	ns	ns	ns
C22:0	ns	ns	-0.43*	ns	ns	ns
MUFA						
C14:1 n-5	-	-	-	-	-	-
C16:1 n-7	ns	ns	ns	ns	ns	ns
C18:1 n-9	ns	ns	0.42**	ns	ns	0.54**
C18:1 n-7	ns	ns	ns	ns	ns	0.45**
C20:1 n-11	ns	ns	ns	ns	ns	ns
C22:1 n-9	-	-	-	-	-	-
PUFA						
C18:2 c9t11	-	-	-	-	-	-
C18:2 n-6	ns	ns	ns	0.35*	ns	ns
C18:3 n-3	0.43**	0.35	ns	ns	ns	0.55**
C20:4 n-6	ns	ns	ns	ns	ns	ns
C22:6 n-3	-	-	-	-	-	-

Note: [ns] correlation coefficient is not significantly different from zero, p>0.05. [*] correlation coefficient is significantly different from zero, p<0.05. [**] correlation coefficient is highly significantly different from zero, p<0.01. [-] Number of paired observations is less than 10.

Table 4. The proportion of fatty acids affected by milk type, sow breed within milk type, and covariate effects of age, parity, and percent fat

Fatty acids	Factors affecting fatty acids					
	Milk type	Breed (Milk type)	Age	Parity	Percent fat	CV (%)
SFA						
C12:0	**	ns	ns	ns	ns	44.78, 49
C14:0	**	ns	ns	ns	ns	26.16, 77
C16:0	**	ns	ns	ns	ns	16.18, 77
C17:0	**	ns	ns	ns	ns	21.49, 47
C18:0	**	ns	ns	ns	** 0.10 ± 0.03	16.88, 77
C20:0	**	ns	ns	ns	ns	22.59 76
C22:0	**	ns	ns	ns	* -0.55 ± 0.21	>100, 67
MUFA						
C14:1 n-5	ns	ns	ns	ns	ns	(10.18, 6)
C16:1 n-7	**	ns	** 0.82 ± 0.28	* -0.30 ± 0.13	ns	32.06, 77
C18:1 n-9	**	ns	* 4.00 ± 1.92	** -1.83 ± 0.85	** 0.89 ± 0.23	16.22, 76
C18:1 n-7	**	ns	ns	ns	ns	35.01, 76
C20:1 n-11	**	*	ns	ns	ns	20.95, 34
C22:1 n-9	ns	ns	ns	ns	ns	(0.16, 8)
PUFA						
C18:2 c9t11	ns	ns	ns	ns	ns	(35.42, 7)
C18:2 n-6	**	ns	ns	ns	ns	26.54, 77
C18:3 n-3	**	ns	ns	ns	ns	27.93, 62
C20:4 n-6	**	ns	ns	ns	ns	28.65, 72
C22:6 n-3	ns	ns	ns	ns	ns	18.62, 11

Note: [ns] no significant differences (p>0.05); [*] significant differences (p<0.05); [**] highly significant differences (p<0.01). The numbers in covariate columns are the regression coefficients and corresponding standard errors. The coefficient of variation (CV) values enclosed in parenthesis indicate that N observations is less than 10.

Only eicosenoic acid (20:1 n-11) was significantly different between breeds within the type of milk (p<0.05). Oleic acid was higher in older sows and colostrum/transient milk with higher fat content, *i.e.,* higher by 4.0% for every year increase in age of sow at farrowing and higher by 0.9% for every increase in percent fat. Oleic acid was, however, lower in colostrum/transient milk from sows at higher parities (*i.e.,* lower by 1.83% for every additional parity). The negative effect of parity on oleic acid may be due to the physiological differences in the reproductive systems of primiparous sows, which could be responsible for lower reproductive performance compared to multiparous sows. Stearic acid (C18:0) and behenic acid (C22:0) were also affected by fat content (*i.e.,* higher C18:0 by 0.10% and lower C22:0 by 0.55% per 1% increase in percent fat).

Major FAs in Sow Colostrum

The major FAs in sow colostrum – representing about 77.95% of total FAs, were oleic acid (32.17%), linoleic acid (25.04%), and palmitic acid (20.74%) (Table 5). These fatty acids were followed by stearic acid C18:0 (4.53%), behenic acid C22:0 (3.99%), palmitoleic acid C16:1 n-7 (2.29%), and myristic acid C14:0 (2.02%). Colostrum contained omega-6 FAs [*i.e.,* linoleic acid or LA and arachidonic acid or AA (C20:4 n-6) at 25.04% and 1.09%, respectively], and insignificant amounts of omega-3 FAs [*i.e.,* α-linolenic acid or ALA (C18:3 n-3) and DHA (C22:6 n-3) at 0.25% and 0.1%, respectively]. Colostrum contained 0.05% CLA while pentadecylic acid (C15:0) was not detected in sow colostrum.

The same major FAs in sow colostrum are also found in human colostrum (Sinanoglou *et al.,* 2017). Human colostrum had higher palmitic acid (26.71%) and oleic acid (34.64%), but lower linoleic acid (9.94%) than sow colostrum (Table 5). Human colostrum is dominated by SFAs (44.53%) followed by MUFAs (38.87%) and PUFAs (11.38%).

Major FAs in Transient Milk

Similar to colostrum, the major FAs in transient milk – representing about 72.39% of total FAs, were oleic acid (34.89%), linoleic acid (18.77%), and palmitic acid (18.73%) (Table 5). Transient milk contained omega-6 FAs [*i.e.,* LA (18.77%) and AA (0.84%)] and omega-3 FAs [*i.e.,* ALA (0.36%) and DHA (0.08%)]. No pentadecylic acid (C15:0), myristoleic acid (C14:1 n-5), and conjugated linoleic acid (C18:2 c9t11) was found in transient milk.

DISCUSSION

Comparison of Major FAs between Sow Colostrum and Transient Milk

Oleic acid was significantly lower in colostrum (32.17%) than in transient milk (36.17%). Palmitic acid and linoleic acid were, however, significantly higher

Table 5. The proportion of fatty acid and FA groups, and FA-based nutritional indices/ratios for sow colostrum and transient milk – in relation to human colostrum

Fatty acids	Sow colostrum	Transient milk	Human colostrum*
SFA			
C12:0	0.25 ± 0.02	0.22 ± 0.03	5.06 ± 0.12
C14:0	2.02 ± 0.08	1.70 ± 0.89	6.85 ± 0.18
C15:0	-	-	0.36 ± 0.01
C16:0	20.74 ± 0.56[a]	18.73 ± 0.59[b]	26.71 ± 0.24
C17:0	0.18 ± 0.01	0.16± 0.01	0.40 ± 0.09
C18:0	4.53 ± 0.13	4.75 ± 0.14	4.95 ± 0.09
C20:0	0.89 ± 0.03[a]	0.76 ± 0.03[b]	0.13 ± 0.01
C22:0	3.99 ± 0.95	4.67 ± 0.87	0.07 ± 0.00
MUFA			
C14:1 n-5	0.06 ± 0.00	-	0.15 ± 0.01
C16:1 n-7	2.29 ± 0.14[b]	2.73 ± 0.14[a]	1.30 ± 0.08
C18:1 n-9	32.17 ± 0.92[b]	34.89 ± 0.97[a]	34.64 ± 0.45
C18:1 n-7	1.52 ± 0.11[b]	2.12 ± 0.11[a]	2.13 ± 0.12
C20:1 n-11	0.13 ± 0.01	0.11 ± 0.01	0.59 ± 0.02
C22:1 n-9	-	0.11 ± 0.01	0.07 ± 0.00
PUFA			
C18:2 c9 t11, CLA	0.05 ± 0.01	-	0.13 ± 0.02
C18:2 n-6, LA	25.04 ± 1.01[a]	18.77 ± 1.07[b]	9.94 ± 0.18
C18:3 n-3, ALA	0.25 ± 0.02[b]	0.36 ± 0.02[a]	0.33 ± 0.02
C20:4 n-6, AA	1.09 ± 0.05[a]	0.84 ± 0.05[b]	0.47 ± 0.02
C22:6 n-3, DHA	0.10 ± 0.01	0.08 ± 0.03	0.51 ± 0.01
SFA	32.60	30.99	44.53
UFA	62.68	60.00	50.25
MUFA	36.17	39.96	38.87
PUFA	26.51	20.05	11.38
n-3 (ALA + DHA)	0.34	0.44	0.84
n-6 (LA + AA)	26.13	19.61	10.41
PUFA/SFA ratio	0.81	0.65	0.26
MUFA/SFA ratio	1.11	1.29	0.87
LA/ALA ratio	102.19	52.73	30.12
n-6/n-3 ratio	76.48	44.87	12.39
Atherogenicity index	0.46	0.43	1.18
Thrombogenicity index	0.85	0.81	1.41
Health-promoting index	2.16	2.33	0.85
h/H ratio	2.55	2.66	1.19

Note: Least-square means for FAs in the same row with different letter superscript letters are significantly different ($p<0.05$). [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. *Adapted from Sinanoglou *et al*. (2017).

in colostrum (20.74% and 25.04%, respectively) than in transient milk (18.73% and 18.77%, respectively).

Total SFA was slightly higher in sow colostrum (32.60%) than in transient milk (30.99%). The difference in total SFA was due to the higher levels of C16:0 in colostrum. On the other hand, the total MUFA was slightly lower in colostrum (36.17%) than in transient milk (39.96%). The difference in total MUFA was mainly due to the lower levels of C18:1 n-9 in colostrum. Total PUFA was also higher in colostrum (26.51%) than in transient milk (20.05%). The difference in total PUFA was largely due to the higher levels of linoleic acid in colostrum.

By comparison, Ren *et al*. (2022) reported that the main FAs found in colostrum and milk of Landrace, Large White, Landrace × Large White crosses in China were C16:0 (21.1% and 24.8%, respectively), C18:1 n-9 (25.1% and 30.9%, respectively), and C18:2 n-6 (38.3% and 23.7%, respectively). On the other hand, Luise *et al*. (2018) showed that the main FAs found in swine colostrum obtained from different breeds (Italian Large White, Italian Landrace, and Italian Duroc) were C16:0 (27.29%), C18:1 n-9 (28.81%), and C18:2 n-6 (23.39%).

Ren *et al.* (2022) also reported slightly lower total SFA in colostrum (27.9%–30.1%) but similar SFAs in milk (29.7%–35.0%); lower total MUFA in colostrum (28.1%–29.3%) but similar MUFAs in milk (39.5%–39.9%); and higher total PUFA in colostrum (40.7%–44.0%) and milk (25.2%–30.8%). The large differences especially in total PUFA, may be attributed to differences in sow nutrition in different pig farms, which

Table 6. Fatty acid groups and fatty acid-based nutritional indices/ratios of colostrum and transient milk from different sow breeds

	Colostrum				Transient milk			
	Landrace	Large White	F1 LDR × LRW	R1 LRW × LDR	Landrace	Large White	F1 LDR × LRW	R1 LRW × LDR
SFA	34.79	31.39	31.37	32.88	32.06	30.18	25.14	26.58
UFA	58.02	61.48	68.80	63.55	59.84	61.23	56.28	62.17
MUFA	33.70	36.24	38.07	37.93	38.68	41.26	37.59	41.98
PUFA	24.32	25.24	30.74	25.62	21.16	19.97	18.70	20.19
n-3 (ALA + DHA)	0.36	0.29	0.36	0.26	0.38	0.43	0.38	0.40
n-6 (LA + AA)	23.92	24.95	30.34	25.29	20.78	19.55	18.32	19.79
PUFA/SFA ratio	0.70	0.80	0.98	0.78	0.66	0.66	0.74	0.76
MUFA/SFA ratio	0.97	1.15	1.21	1.18	1.21	1.37	1.50	1.58
LA/ALA ratio	23.08	24.06	100.19	91.54	20.24	19.18	17.85	19.44
n-6/n-3 ratio	65.72	86.63	85.24	96.15	54.54	45.88	48.72	49.22
Atherogenicity index	0.49	0.47	0.41	0.48	0.45	0.41	0.45	0.41
Thrombogenicity index	0.90	0.84	0.76	0.90	0.88	0.77	0.82	0.80
Health-promoting index	2.05	2.12	2.45	2.06	2.20	2.44	2.22	2.43
h/H ratio	2.41	2.54	2.87	2.39	2.52	2.82	2.54	2.75

Note: [F1 LDR × LRW] crossbred sows with Landrace sire and Large White dam; [R1 LRW × LDR cross] crossbred sows with Large White sire and Landrace dam; [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.

may significantly affect major PUFAs, especially linoleic acid and α-linolenic acid. In general, FAs abundant in the sow diets are also abundant in milk fat. For example, Bai *et al.* (2017) showed that the increases in the concentrations of linoleic acid and α-linolenic acid were more pronounced in the colostrum and milk from sows fed soybean oil than in the colostrum and milk from sows fed coconut oil and palm oil.

Comparison of FA Groups between Sow Breeds

While total SFA and omega-3 FAs in colostrum were higher in Landrace sows (34.79% and 0.36%, respectively), the total MUFA was higher in Large White sows (36.24%) (Table 6). Total PUFA in colostrum was, however, similar in the two purebreds. Crossbred sows (*i.e.,* F1 "LDR × LRW" and R1 "LRW × LDR") had lower average SFA but higher average MUFA and PUFA than purebred sows, suggesting the possible heterotic effects (due to dominance and epistasis) on the different FA groups in sow colostrum. For transient milk, the differences in total SFA, MUFA, and PUFA between Landrace and Large White sows and between purebred and crossbred sows were small (*i.e.,* less than 2%). In practice, the FA profiles of transient and mature milk before the piglets are weaned from their dams may be enhanced by changing the sow lactation diet and supplemental feeding of the growing piglets.

By comparison, Ren *et al.* (2022) reported that Landrace sows had the highest SFA in colostrum (30.1%) and milk (35.0%) and the highest MUFA in colostrum (29.3%) and milk (39.9%). The PUFA was the highest in colostrum of Large White sows (44.0%), and the highest in the milk of Landrace × Large White crossbred sows (30.8%).

FA-based Nutritional Indices/Ratios

The difference in nutritional indices/ratios related to human cardiovascular health between colostrum and transient milk and among sow breeds are presented in Tables 5 and 6, respectively.

PUFA/SFA ratio. The PUFA/SFA ratio is an index normally 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 higher for sow colostrum (0.81: 1) than for transient milk (0.61: 1). The PUFA/SFA ratios in both sow colostrum and transient milk were higher than the computed PUFA/SFA for human colostrum (*i.e.,* 0.26: 1) as reported by Sinanoglou *et al.* (2017). The high PUFA/SFA ratio in sow colostrum/milk was due to the higher linoleic acid and arachidonic acid levels. The high MUFA/SFA ratio was due to the high proportion of oleic acid.

While the PUFA/SFA ratio in colostrum was higher for Large White sows (0.80: 1) than for Landrace sows (0.70: 1), the PUFA/SFA ratio in transient milk was similar for Landrace and Large White sows. However, the F1 "LDR × LRW" and R1 "LRW × LDR" crossbred sows had a higher average PUFA/SFA ratio in both colostrum and transient milk than those from purebred sows, suggesting the importance of non-additive genetic effects on PUFA/SFA ratio.

LA/ALA ratio. Linoleic acid (LA) and α-linolenic acid (ALA) are considered essential FAs because humans cannot synthesize them. The LA/ALA ratio describes the balance between LA and ALA as they compete for the same desaturase and elongase enzymes, which they use to synthesize long-chain unsaturated FAs. A high LA/ALA ratio implies faster rates of synthesis of α-linolenic acid, which are not present in baby food and infant formula. The LA/ALA ratio in the diet has no significant importance on adults since tissues of adults have a lower rate of synthesis of α-linolenic acid than those of infants. Hence, a minimum reference value (within 5–15: 1) is usually set to promote the nutritional value of baby food and infant formula (Chen & Liu, 2020).

In this study, LA/ALA ratio was higher in sow colostrum (102.19: 1) than in transient milk (52.73: 1). While the LA/ALA ratio in colostrum and transient milk was similar in Large White and Landrace sows, the F1 "LDR × LRW" and R1 "LRW × LDR" crossbred sows had higher average LA/ALA ratio in colostrum than those of purebred sows. For transient milk, however, the differences in LA/ALA ratio between Landrace and Large White sows and between purebred and crossbred sows were small (*i.e.,* less than 2%).

The LA/ALA ratio in sow colostrum was about 3.4 times higher than the computed LA/ALA ratio for human colostrum (*i.e.,* 30.12: 1), as was reported by Sinanoglou *et al.* (2017).

n-6/n-3 ratio. The Omega-6/Omega-3 (n-6/n-3) ratio is an important determinant of PUFAs and their effects on inflammatory diseases. As precursors to eicosanoids, the omega-6 FAs (i.e., LA and AA) and omega-3 FAs (*i.e.,* ALA and DHA) have important roles in regulating inflammation. The eicosanoids derived from omega-6 FAs are generally pro-inflammatory, while eicosanoids derived from omega-3 FAs are anti-inflammatory.

The high n-6/n-3 ratio associated with the greater metabolism of the omega-6 FAs compared with omega-3 FAs is related to the increases in chronic inflammatory 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 regard, the optimal dietary intake of the n-6/n-3 ratio should be around 1–4: 1. A lower n-6/n-3 ratio (1–2: 1) may reduce the risk of many chronic diseases. However, the optimal ratio may vary with the disease under consideration depending on the degree of disease severity resulting from the genetic predisposition.

In this study, the omega-6 FAs were higher in sow colostrum (26.13%) than in transient milk (19.61%). On the other hand, the differences in n-3 PUFA between colostrum (0.34%) and transient milk (0.44%) were small. The n-6/n-3 ratio was higher (*i.e.,* less balanced) in sow colostrum (76.48: 1) than in transient milk (44.87: 1).

While the n-6/n-3 ratio in colostrum was lower in Landrace (65.72: 1) than in Large White sows (86.63: 1), the crossbred sows had a higher average n-6/n-3 ratio than that of purebred sows. For transient milk, the n-6/n-3 ratio was higher in Landrace (54.54: 1) than in Large White sows (45.88: 1). However, the differences in n-6/n-3 ratio between purebred and crossbred sows were small (*i.e.,* less than 2%).

The n-6/n-3 ratio in sow colostrum was about 6.2 times higher (*i.e.,* less balanced) than the computed n-6/n-3 ratio for human colostrum (*i.e.,* 12.39: 1) as was reported by Sinanoglou *et al.* (2017).

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.,* lower tendency to form fatty plaques in the arteries) (Chen & Liu, 2020).

In this study, the IA was lower (*i.e.,* greater health benefit) in transient milk (0.43) than in colostrum (0.46). The difference in IA values, however, was small. The atherogenicity potentials of both colostrum and transient milk were lower in Large White sows (0.47 and 0.41, respectively) than in Landrace sows (0.49 and 0.45, respectively). The average IA values of colostrum and transient milk were similar for purebred and crossbred sows.

The atherogenicity potential of sow colostrum was about 2.7 times lower (*i.e.,* lower risk of coronary heart disease benefit) than the computed IA for human colostrum (*i.e.,* 1.18) reported by Sinanoglou *et al.* (2017). This result could be due to the lower levels of SFAs and higher levels of PUFAs – linoleic acid and arachidonic acid in sow colostrum.

Thrombogenicity index. The index of thrombogenicity (IT) is a measure of 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.,* lower tendency to form clots in blood vessels) (Chen & Liu, 2020).

In this study, the IT was lower (*i.e.,* greater health benefit) for transient milk (0.81) than in colostrum (0.85). The difference in IT values, however, was small. The thrombogenicity potential of both colostrum and transient milk was lower in Large White sows (0.84 and 0.77, respectively) than in Landrace (0.90 and 0.88, respectively). Crossbred sows had slightly lower average IT in both colostrum and transient milk than purebred sows.

The thrombogenicity potential of sow colostrum was about 1.7 times lower (*i.e.,* lower risk of coronary heart disease benefit) than the computed IA for human colostrum (*i.e.,* 1.41), as was reported by Sinanoglou *et al.* (2017). This result could mainly be due to the lower levels of myristic acid and palmitic acid, and higher levels of linoleic acid in sow colostrum.

Health-promoting index. The health-promoting index (HPI) is the inverse of the atherogenicity index. In dairy products such as milk and cheese, the HPI values range from 0.16–0.68 (Chen & Liu, 2020). A high HPI value in dairy products suggests more benefits for human health.

In this study, the HPI was higher in transient milk (2.33) than in colostrum (2.16). The HPI for both colostrum and transient milk was higher in Large White sows (2.12 and 2.44, respectively) than in Landrace (2.05 and 2.20, respectively). The average HPI values of colostrum were higher for crossbred sows than for purebred sows. However, the average HPI values of transient milk were similar for purebred and crossbred sows.

The HPI of sow colostrum was about 2.5 times higher (*i.e.,* more beneficial to human health) than the computed HPI for human colostrum (*i.e.,* 0.85) as was reported by Sinanoglou *et al.* (2017).

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). The h/H ratio in dietary fats may range from 0.32–1.29: 1. A high h/H value suggests greater benefits for human health (Chen & Liu, 2020).

In this study, the h/H ratio was higher in transient milk (2.66: 1) than in colostrum (2.55: 1), suggesting that consumption of transient milk from sows may lower blood cholesterol levels. The h/H ratio for both colostrum and transient milk was higher in Large White sows (2.54: 1 and 2.82: 1, respectively) than in Landrace (2.41: 1 and 2.52: 1, respectively). The average h/H ratio of colostrum was higher for crossbred sows than for purebred sows. However, the average h/H ratio of transient milk was similar for purebred and crossbred sows.

The h/H ratio of sow colostrum was about 2.5 times higher (*i.e.,* more beneficial to human health) than the computed h/H ratio for human colostrum (*i.e.,* 1.19: 1), as was reported by Sinanoglou *et al.* (2017). The higher h/H ratio (and HPI values) in sow colostrum are due mainly due to its lower levels of lauric acid, myristic acid, and palmitic acid, and higher levels of linoleic acid compared to human colostrum.

Overall, the development of sow colostrum-based supplements that may provide medical and nutritional benefits to human cardiovascular health may obtain colostrum from the numerous crossbred sows currently used in the commercial production of market hogs. However, the production of colostrum all year round in commercial quantities will be limited as the amount of colostrum produced by a sow is less than 4% of the total milk that may be produced in a one-month lactation period or just before weaning. The amount of available milk used for this purpose will also be low since much of the milk is first fed to the piglets.

CONCLUSION

Colostrum from crossbred sows had better FA-based nutritional value than from purebred sows and may be used to prepare milk replacer formulations for piglets. On the other hand, transient milk, especially from Large White sows, appears to be more beneficial for human cardiovascular health and may be considered in the development of sow milk-based supplements in the human diet.

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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