Italian Journal of Animal Science

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tjas20

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To cite this article: Francesco Palumbo, Giuseppe Bee, Paolo Trevisi & Marion Girard (2023) Decreasing the level of hemicelluloses in sow’s lactation diet affects the milk composition and post-weaning performance of low birthweight piglets, Italian Journal of Animal Science, 22:1, 250-262, DOI: 10.1080/1828051X.2023.2181108

To link to this article: https://doi.org/10.1080/1828051X.2023.2181108

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Published online: 28 Feb 2023.

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ITALIAN JOURNAL OF ANIMAL SCIENCE
2023, VOL. 22, NO. 1, 250–262
https://doi.org/10.1080/1828051X.2023.2181108

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Decreasing the level of hemicelluloses in sow's lactation diet affects the milk composition and post-weaning performance of low birthweight piglets

Francesco Palumbo[a,b], Giuseppe Bee[a], Paolo Trevisi[b] and Marion Girard[a]

[a]Agroscope, Swine Research Group, Posieux, Switzerland; [b]Dipartimento di Scienze e Tecnologie Agro-alimentari (DISTAL), University of Bologna, Bologna, Italy

ABSTRACT

Hemicelluloses (HC) are polysaccharides constituents of the cell walls of plants. They are fermented in the gut to produce volatile fatty acids (VFA). The present study investigated the effects of decreasing HC level in a sow's lactation diet on sow performances, offspring development and milk composition. From 110 days (d) of gestation until weaning (26 ± 0.4 d post-farrowing), 40 Swiss Large White sows were assigned to one of the four dietary treatments: (1) T13 (HC: 127 g/kg), (2) T11 (HC: 114 g/kg), (3) T9 (HC: 94 g/kg) and (4) T8 (HC: 80 g/kg). Milk was collected at 3 and 17d of lactation. At birth, piglets were divided into two groups according to their birthweight (BtW): normal (N-BtW; BtW >1.20 kg) or low (L-BtW; BtW ≤ 1.20 kg). Decreased HC levels in the maternal diet linearly increased ($p \leq .05$) the body weight of L-BtW piglets at two weeks post-weaning and linearly decreased ($p \leq .05$) diarrhoea incidence and duration in this category. The concentrations of copper, threonine and VFA, as well as the proportion of butyrate, in milk linearly increased ($p \leq .05$), whereas lactose content linearly decreased ($p \leq .05$) with decreased HC in the maternal diet. The present study provides evidence that decreasing HC level in a sow's lactation diet can positively affect the composition and VFA profile of milk and ultimately favour the growth and health of L-BtW piglets.

HIGHLIGHTS

- The results of this study showed that decreasing the level of hemicelluloses in a sow's lactation diet modified milk composition and had positive effects on the post-weaning performance of low birthweight piglets.
- This study highlighted the role of dietary fibres in the maternal diet to alleviate body weight variations at two weeks post-weaning.
- Nevertheless, before advising pig producers, further research should elucidate the optimal level of hemicelluloses for lactating sows.

ARTICLE HISTORY
Received 21 October 2022
Revised 10 January 2023
Accepted 10 February 2023

KEYWORDS
Dietary fibres; lactose; pigs; volatile fatty acids; butyrate

Introduction

Hemicelluloses (HC) represent a complex group of polysaccharides present in the cell walls of all plants, consisting mainly of pentoses (D-xylose and D-arabinose), hexoses (D-galactose, D-glucose and D-mannose) and uronic acids that can be estimated as the difference between NDF and ADF (Van Soest et al. 1991; Huang et al. 2021). As part of dietary fibres (DF), they can resist digestion by endogenous enzymes of the gut. Thus, they can reach the large intestine and promote the growth and activity of beneficial bacteria that produce volatile fatty acids (VFA) (Lattimer and Haub 2010). These latter, namely acetate, propionate and butyrate, provide up to 28% of the energy requirements in growing pigs and even more in sows, where they can be absorbed and transferred to the milk and serve as an energy source for milk synthesis (Noblet and Le Goff 2001; Tian et al. 2020). A previous study focussed on increasing the level of DF in a sow's gestation diet showed that adding up to 20% DF increases colostrum fat content, as well as colostrum intake, of low birth weight (BtW) piglets (0.6 kg q BtW <0.9 kg) and decreases litter mortality during the suckling period (Loisel et al. 2013). These positive effects on growth and survival are in line with the findings of Paßlack et al. (2015) who reported that the inclusion of 3% inulin, a source of DF offered to lactating sows

CONTACT Marion Girard marion.girard@agroscope.admin.ch

Supplemental data for this article can be accessed online at https://doi.org/10.1080/1828051X.2023.2181108

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positively affected the development and gut health of their litters.

Apart from the quantity of DF provided, the beneficial effects of DF is also related to their physiochemical properties such as their solubility in water and their intestinal fermentability. For instance, due to a slower fermentability compared to soluble dietary fibres (SDF), the majority of the insoluble dietary fibres (IDF) reach the large intestine and stimulate the growth of commensal and probiotic bacteria such as Ruminococcus, Faecalibacterium, Lactobacillus and Bifidobacterium (LeBlanc et al. 2017). The large intestine acts then as a fermentation chamber producing VFA, CO2, H2 and other carboxylic acids (Lattimer and Haub 2010). Conversely, SDF are easily fermented and may be completely degraded at the end of the small intestine (Houdijk et al. 2002). Depending on the plants, HC might be considered as a source of SDF (Jiménez-Escrig and Sánchez-Muniz 2000). A previous study in growing pigs reported that decreasing HC level increased VFA produced in the ileum (Zhao et al. 2019). However, to our knowledge, little is known about the effects of HC level in lactating sows. Therefore, the present study aims to fill this gap by comparing four diets characterised by similar total DF content but different HC levels by varying the sources of DF. We hypothesised that decreasing the level of HC while maintaining a similar total DF level in sow's lactation diet would affect the IDF to SDF ratio and by that impact gut fermentation particularly in the large intestine and ultimately modify milk composition.

Material and methods

Animals, housing and treatments

The experiment was conducted during late gestation and lactation of 40 Swiss Large White sows from five farrowing batches. Approximately 10 d before the expected time of farrowing, sows were moved to farrowing rooms arranged with individual 7.1 m^2 farrowing crates, consisting of a 5.89 m^2 concrete solid floor and a 1.21 m^2 concrete slatted floor. Each crate was equipped with an electronic sow feeder (Schauer Spotmix, Schauer Agrotronic GmbH, Austria), a nipple drinker and a heated covered area for piglets. The ambient temperature was maintained at 24 °C, and artificial lights were on from 0800 h to 1700 h. On day 110 of gestation, the sows were randomly allocated to one of the four experimental lactation diets based on parity (mean ± SEM: 3.5 ± 0.7) and BW (mean ± SEM: 286.5 ± 13.6 kg). Parturition was induced when the gestation period exceeded 116 d with an intramuscular injection of 1 mL (0.25 g/mL) of cloprostenol (Estrumate®, MSD Animal Health GmbH, Luzern, Switzerland). Within the first 24 h following birth, piglets were identified by an individual ear tag and received an iron injection (Feridex® 10%, AMAG Pharmaceuticals, Inc., Waltham, USA). Piglets weighing less than 800 g at birth were excluded from the experiment. To adjust litter size to an average of 12 piglets per sow, cross-fostering was carried out within the same dietary treatment and only on male piglets 24 h post-farrowing. After anaesthetisation, the male piglets were castrated in the second week. Piglets were weaned on day 25.7 ± 0.44 (mean ± SEM) of age but were kept in their respective farrowing crates until 2 weeks post-weaning. The heating nest temperature was set at 40 °C following birth and then gradually decreased by 0.5 °C per day to reach a final temperature of 32 °C.

Diets and feeding

The experimental diets were formulated to be isonitrogenous and isocaloric (Table 1) and to differ in DF sources and HC content: (1) T13 (HC: 127 g/kg), (2) T11 (HC: 114 g/kg), (3) T9 (HC: 94 g/kg) and (4) T8 (HC: 80 g/kg). The daily feed allowance was calculated according to the current Swiss feeding recommendations for pigs (Agroscope 2018). Sows had ad libitum access to water and were provided with moderate quantities of straw bedding, as required by Swiss legislation. During the end of gestation, feed allowance was on average 3.04 ± 0.16 kg (mean ± SEM). While, during lactation, the feed allowance was gradually increased by 0.5 kg/d until ad libitum feeding on day 12 of lactation approximatively. All diets were delivered in pelleted form three times per day in three equal meals using a computerised feed delivery system (Schauer Spotmix, Schauer Agrotronic GmbH, Austria). Throughout the experiment, the feed refusals of the sows were weighed daily to calculate actual feed intake. From day 18.7 ± 0.44 of age (mean ± SEM) to 2 weeks post-weaning (mean ± SEM: day 39.7 ± 0.44 of age), piglets had ad libitum access to a post-weaning standard starter diet and water. The post-weaning starter diet contained 170 g/kg crude protein, 58 g/kg fat, 50 g/kg crude fibre and 14 MJ/kg digestible energy.

Sow and piglet performance

The BW of the sows, body condition score (BCS) and backfat thickness were recorded at the 110th day of

Table 1. Ingredients and composition of the sow's lactation diet.

Item	Dietary treatments[a]			
	T13	T11	T9	T8
Ingredients (%)				
Barley, ground	54.400	38.700		4.700
Oat flakes			4.000	18.200
Corn, ground	10.300		26.900	16.000
Rye		25.000	10.000	
Wheat, ground			13.100	15.000
Wheat starch	4.000	4.000	4.000	4.000
Molasses				4.000
Animal fat RS 65	2.400	2.400	3.000	3.800
Potato protein	10.000	10.000	10.000	10.000
Soybean meal	10.000	10.000	10.000	10.000
Flaxseed Meal	0.600			
Rapeseed meal		0.400		1.700
Oat hulls			4.000	8.000
Lupin			2.500	
Wheat bran			4.000	
Beet pulp	3.000	5.000	4.000	
L-lysine-HCL	0.070	0.057	0.057	0.056
DL-methionine	0.200			
L-threonine	0.050			0.050
L-tryptophan	0.020	0.006	0.013	0.003
Dicalcium phosphate	0.940	0.700	0.820	0.850
Calcium carbonate	1.570	1.380	1.390	1.470
Salt	0.590	0.520	0.420	0.410
Pellan[b]	0.400	0.400	0.400	0.400
Celite	1.000	1.000	1.000	1.000
Premix[c]	0.400	0.400	0.400	0.400
Natuphos 5000 G[d]	0.010	0.010	0.010	0.010
Gross chemical composition analysed (g/kg as fed)				
Dry matter	900	894	897	900
Crude protein	193	191	192	196
Fat	51	46	57	60
Crude fibre	43	43	47	46
Ash	63	61	60	63
NDF	184	174	163	154
ADF	57	60	69	79
Hemicelluloses[e]	127	114	94	80
Total dietary fibres	210	227	220	203
Low-molecular-weight dietary fibres	18	23	18	14
Soluble dietary fibres	43	44	35	28
Insoluble dietary fibres	149	160	167	161
IDF/SDF[f]	3.460	3.630	4.770	5.750
Calcium	9.400	9.400	9.300	8.700
Phosphorus	5.000	4.600	5.000	4.700
Gross chemical composition calculated				
Digestible energy (MJ/kg)	14.100	14.100	14.100	14.100
Digestible phosphorus (g/kg as fed)	3.100	2.800	2.800	2.800
Digestible essential amino acids (g/kg as fed)				
Lysine	9.600	9.600	9.600	9.600
Methionine	4.900	2.900	3.000	3.000
Threonine	6.900	6.300	6.400	6.900
Tryptophan	2.000	1.800	1.800	1.800

[a] T13 = Sow's lactation diet containing 13% of hemicelluloses; T11 = Sow's lactation diet containing 11% of hemicelluloses; T9 = Sow's lactation diet containing 9% of hemicelluloses; T8 = Sow's lactation diet containing 8% of hemicelluloses.

[b] Pellet binding aid: Pellan, Mikro-Technik, Bürgstadt, Germany.

[c] Supplied per kg of diet: vitamin A, 8000 IU; vitamin D3, 800 IU; vitamin E, 40 mg; menadione, 2 mg; thiamine, 2 mg; riboflavin, 5 mg; biotin, 0.1 mg; niacin, 20 mg; pantothenic acid, 20 mg; iodine (as calcium iodate), 0.55 mg; copper (as copper sulphate), 7 mg; manganese (as manganese oxide), 20 mg; zinc (as zinc oxide), 55 mg; selenium (as sodium selenite), 0.2 mg.

[d] Phytase supplemented with 500 units of *Aspergillus niger* phytase/kg diet.

[e] Hemicellulose: calculated as the difference between NDF and ADF.

[f] Ratio of insoluble to soluble dietary fibre.

ADF: acid detergent fibre; NDF: neutral detergent fibre.

gestation and on the day of farrowing and weaning. Weight loss during lactation was calculated as the weight difference between farrowing and weaning. Based on visual observation and palpations, BCS was determined according to a scale ranging from 1 (very thin) to 6 (obese) points (Dourmad et al. 2001), including intermediate values of 0.33 points. Briefly, the trained personnel assessed sows by palpating the shoulders, ribs, backbone and hips, followed by visual observation. Backfat thickness was measured on each side at 65 mm of the dorsal midline at the level of the last rib (P2) using a digital ultrasound back-fat indicator (Renco Lean Metre Digital Backfat Indicator, Renco Corporation, Minneapolis, Minnesota, USA). Backfat thickness loss during lactation was then calculated as the difference between backfat thickness measurements during farrowing and weaning. At farrowing, the number of born alive, stillborn and mummified piglets were recorded within each litter. Farrowing was recorded using a digital video recorder to estimate the farrowing duration, which is defined as the time span between the time of birth of the first and last piglet of the litter. At birth, the piglets were individually weighed, and crown-to-rump length and body circumference were recorded. Piglets were then individually weighed 5 and 16 d postpartum, during weaning (mean ± SEM: 25.7 ± 0.44 d of age) and at 1 (mean ± SEM: 32.7 ± 0.44 d of age) and 2 weeks post-weaning (mean ± SEM: 39.7 ± 0.44 d of age). The average daily gain (ADG) and litter weight during birth and weaning were calculated from these data. Milk yield was calculated as the individual piglet gain summed in the same litter multiplied by a numerical coefficient of 4.2 (Van der Peet-Schwering et al. 1998). The indices of body conformation were calculated based on the measurements of the individual BtW and the crown-to-rump length. The body mass index was calculated as the ratio of BtW to the squared value of the crown-to-rump length, and the ponderal index was calculated as the ratio of BtW to the cubic value of the crown-to-rump length (Hales et al. 2013). In addition, piglets were divided into two BtW groups: normal (N-BtW; BtW >1.20 kg) or low (L-BtW; BtW ≤ 1.20 kg). From 1 week before weaning onwards, feed intake and refusals (including feed waste) per pen as well as the occurrence of diarrhoea were recorded daily. Diarrhoea incidence was determined according to a daily faecal score assessed using a scale from 0 = no diarrhoea to 1 = diarrhoea. The percentage of diarrhoea per group was calculated as the sum of piglets with a faecal score of one divided by the total number of piglets.

Sample collection

Within each farrowing series, feed samples of the four diets were collected weekly and pooled over the experimental period to determine the chemical composition. On days 3 and 17 of lactation, milk samples were manually collected from all functional teats after intramuscular injection of 2 ml of oxytocin (Intertocine-S, MSD Animal Health GmbH, Luzern, Switzerland). Before milking, the piglets were temporarily isolated from the sow for 2 h, and the teats were cleaned with humid wipes. One aliquot of milk was refrigerated at 5 °C with 4 mg of bronopol to determine somatic cell concentration, and three aliquots were immediately stored at −20 °C for further analysis.

Analytical methods

Feed analysis

After being ground to pass a 1-mm screen (Brabender rotary mill; Brabender GmbH & Co. KG, Duisburg, Germany), feed samples were analysed for dry matter content by heating at 105 °C for 3 h followed by incineration at 550 °C until a stable mass was reached to determine the ash content according to ISO 5984:2002 (prepASH, Precisa Gravimetrics AG, Dietikon, Switzerland). An inductively coupled plasma optical emission spectrometer (ICP-OES, Optima 7300 DV; Perkin-Elmer, Schwerzenbach, Switzerland) was used to measure mineral content (European Standard EN 15510:2008). The CP content was calculated as nitrogen (N) content multiplied by a coefficient of 6.25, where N was determined with the Dumas method (ISO 16634–1:2008). Fat content was extracted with petrol ether after acid hydrolysis (ISO 6492:1999). Different categories of fibres were analysed by standard protocols. Crude fibre content was determined gravimetrically (ISO 6865:2000) by incineration of residual ash after acid and alkaline digestions using a fibre analyser (Fibretherm Gerhardt FT-12, C. Gerhardt GmbH & Co. KG, Königswinter, Germany). The NDF and ADF contents (ISO 16472:2006 for NDF and ISO 13906:2008 for ADF) were analysed with the same fibre analyser (Fibretherm Gerhard FT-12, C. Gerhardt GmbH & Co. KG, Konigswinter, Germany) and were expressed without residual ash. NDF determination was evaluated with heat-stable amylase and sodium sulphite and expressed without residual ash after incineration at 600 °C for 3 h. The contents of SDF, IDF and low-molecular-weight DF were measured according to AOAC Method 2011.25, and the total DF content was calculated as the sum of the three aforementioned types of DFs.

Milk analysis

The dry matter of the frozen milk samples was determined after freeze-drying (Christ DELTA 2-24 LSC, Kühner AG, Birsfelden, Switzerland) for 70 h. Subsequently, freeze-dried samples were milled with a mortar. Residual dry matter, ash, mineral and nitrogen contents were analysed as previously described for the feed chemical analysis, except that CP was expressed as N × 6.38. Except for tryptophan, all amino acids were determined as described in ISO 13903:2005. Briefly, after oxidation, 24 h of acid hydrolysis occurred with 6 M HCl and derivatization with AccQ-Tag Ultra reagent (Waters Corporation, Milford, USA USA), the amino acid profile was determined by ultra-high-performance liquid chromatography (UHPLC) coupled with a UV detector (Vanquish, Thermo Scientific, Reinach, Switzerland. Tryptophan content was quantified by HPLC (LC 1290 Infinity II LC System, Agilent Technologies, USA) according to ISO 13904:2016. Gross energy content was determined by combustion in a calorimetric vessel under pure oxygen condition using an adiabatic bomb calorimeter (AC600 Semi-Automatic Calorimeter, Leco Corporation, USA) (ISO 9831:1998). Lactose content was determined by enzymatic testing with β-galactosidase and galactose dehydrogenase (Enzytec TM Liquid Lactose/D-Galactose Ref. No. E8110, R-Biopharm AG, Darmstadt, Germany). Somatic cells count (ISO 13366-2) was determined by flow cytometry (Somacount FC, Bentley Instruments Inc., USA). Fatty acid methyl esters, as described by Kragten et al. (2014), and the VFA profile (ISO 15884:2002) (ISO 15885:2002) were determined by gas-liquid chromatography (Gaschromatograph Series II Agilent 6850, Agilent Technologies 2000, USA and Gaschromatograph Serie Agilent 6890, Agilent Technologies 2000, USA, respectively). Fat content was determined as total fatty acids multiplied by a coefficient of 1.05.

Statistical analysis

Due to health problems that could not be related to the dietary treatment, one T9 sow was excluded from the experiment. Data were analysed by ANOVA using the 'lme' and the 'glmmPQL' function of the nlme package of R Studio (version 4.0.2 for Windows). Regarding sow performance, milk composition and VFA profile, the sow was the experimental unit; the pen was the experimental unit regarding piglet feed intake and litter performance; and the piglet was the experimental unit of piglet's individual performance, days and percentage of diarrhoea. Linear regression models, including the treatment and the farrowing batch as fixed effects, were used to fit data related to sow performance, litter performance, piglet feed intake and days with diarrhoea. Data related to piglets' individual performance were analysed using a linear mixed-effects model, including the treatment and the farrowing batch as fixed effects and the sow as random effects. Milk composition and VFA profile were analysed with a linear mixed-effects model and fitted in repeated measurements, including the treatment, the farrowing batch, the sampling day, and the interaction between the treatment and sampling day as fixed effects and the sow as a random effect. Before analysis, logarithmic transformation was applied to the milk fatty acid and milk VFA data due to the non-normality of the residuals. The percentage of diarrhoea was analysed using a generalised linear mixed model using Penalised Quasi-Likelihood, including the treatment, the farrowing batch and the day as fixed effects and the piglet as a random factor. Orthogonal polynomial contrasts were implemented to evaluate the linear or quadratic effects of decreasing HC level. The results are expressed as the least square means ± SEM. Linear and quadratic effects were considered significant at $p \leq .05$.

Results

Sows' performance

The sow BW, BCS and backfat thickness on day 110 of gestation and during farrowing and weaning were not influenced by the dietary treatment, resulting in similar weight and backfat thickness losses during the lactation period (Table 2). Daily feed intake in the pre-farrowing period and during lactation did not differ between treatments. Fibre intake was partially influenced by dietary treatments. In both the pre-farrowing and lactation periods, the NDF, HC, (linear effects; $p < .01$), low-molecular-weight DF and SDF intake decreased (linear and quadratic effects; $p < .01$), and the ADF intake increased (linear effect; $p < .01$) with decreasing HC levels in the diet. A quadratic effect ($p \leq .04$) of the HC level was found in the diets on the intake of total DFs in the pre-farrowing and lactation periods (Supplementary Table 1). At birth, litter traits, such as total born, born alive and stillborn piglets, did not differ, leading to comparable litter weights in the four treatments. Likewise, the dietary treatments had no effect on the total number of piglets weaned and, consequently, on litter weight at weaning. The farrowing duration was not influenced by dietary treatments. During the entire lactation period, milk yield was not influenced by the dietary treatments, with an average estimated production of 10.38 kg/d per sow (Table 2).

Piglets' individual performance

Body characteristics, such as body circumference, crown-to-rump length, body mass index and ponderal

Table 2. Effect of decreasing hemicelluloses level in lactation diet on sow's performance.

	[a]Dietary treatments					[b]Contrasts	
Item	T13	T11	T9	T8	SEM	*L*	*Q*
Sows							
Number of sows, *n*	10	10	9	10			
Range of parity, *n*	3.800	3.800	3.500	3.500	0.690	0.510	0.990
Farrowing duration, min	308	337	321	262	70.700	0.540	0.440
Body weight, kg							
D110	284	291	284	287	13.600	0.710	0.890
Farrowing	264	267	269	272	14.100	0.670	0.990
Weaning	233	238	248	246	12.500	0.390	0.780
Weight loss in lactation, kg	30.600	28.700	20.900	26.100	2.580	0.190	0.300
BCS, *n*							
D110	4.090	4.100	4.030	3.830	0.129	0.790	0.180
Farrowing	3.580	3.590	3.400	3.640	0.148	0.960	0.400
Weaning	2.710	2.620	2.810	2.940	0.246	0.420	0.620
Backfat thickness, mm							
D110	13.800	14.800	12.700	15.800	0.880	0.310	0.230
Farrowing	13.700	14.600	12.700	15.600	0.880	0.340	0.240
Weaning	11.300	11.900	11.500	12.900	0.710	0.180	0.520
Backfat thickness loss in lactation, mm	2.380	2.660	1.250	2.670	0.505	0.820	0.240
Milk yield, kg/d	10.610	10.850	10.090	9.970	0.720	0.410	0.790
Feed intake, kg/d							
Pre-farrowing	2.930	3.030	3.030	3.000	0.155	0.750	0.680
Lactation	5.670	5.930	5.770	5.870	0.237	0.690	0.730
Suckling piglets							
Number of piglets per litter, *n*							
Total born[c]	13.500	13.700	13.500	14.300	1.120	0.650	0.760
Born alive[c]	12.800	12.400	11.400	12.700	1.270	0.820	0.490
Stillborn	0.700	1.300	2.100	1.600	0.650	0.220	0.400
After cross-fostering	11.400	11.400	11.500	11.600	0.790	0.850	0.910
Weaned	10.700	10.900	11.300	10.700	0.760	0.940	0.600
Litter weight, kg							
At birth	20.500	20.500	21.100	20.300	1.630	0.990	0.810
At weaning	81.900	83.900	78.000	79.400	5.500	0.590	0.960

[a] T13 = Sow's lactation diet containing 13% of hemicelluloses; T11 = Sow's lactation diet containing 11% of hemicelluloses; T9 = Sow's lactation diet containing 9% of hemicelluloses; T8 = Sow's lactation diet containing 8% of hemicelluloses.

[b] Contrasts: L: Linear; Q: Quadratic.

[c] Including piglets weighing less than 800 g at birth.

BCS: body condition score; D110: 110 days of gestation.

index, were not affected by the lactation diet of the sows (Supplementary Table 2). Similarly, piglet BW development, ADG and feed intake were not affected by the dietary treatments. During the first week post-weaning, the incidence of diarrhoea and the number of days with diarrhoea were similar among the treatments. By contrast, during the second-week post-weaning, a quadratic increase ($p \leq .05$) in the incidence of diarrhoea and the number of days with diarrhoea was observed with decreasing HC level. When focussing on the two BtW categories, the effect of the sow diets in the L-BtW group showed interesting observations (Table 3). The BtW, the BWs until one week post-weaning and in accordance the ADG in this period were similar among the experimental treatments for L-BtW piglets. By contrast, the decrease in HC level in the sow diets increased (linear effect; $p \leq .04$) the BW and the ADG in the second week post-weaning and the overall ADG from birth to two weeks post-weaning of L-BtW piglets. In the first week post-weaning, the dietary treatments did not affect either the incidence of diarrhoea or the days with diarrhoea of L-BtW piglets. In the second week post-weaning, the incidence of diarrhoea and days with diarrhoea linearly decreased ($p < .01$) with decreased HC level in the maternal diet. Except for the linear increase in the incidence of diarrhoea and increase in the number of days with diarrhoea in the second-week post-weaning ($p < .01$) with decreasing HC level, no dietary effects on growth traits were observed in N-BtW pigs (Supplementary Table 3).

Milk composition

Throughout lactation, no dietary treatment and sampling day interaction was found (data not shown). At days 3 and 17 of lactation, DM, ash, protein and somatic cell count, as well as milk yield estimated from farrowing to day 3 and from day 4 to day 17 of lactation, were similar among dietary treatments (Table 4). With a decreasing HC level, milk lactose content linearly decreased ($p < .01$). Regarding mineral levels in the sow milk, calcium, phosphorus, sodium, magnesium and zinc contents remained similar among

Table 3. Effect of decreasing hemicelluloses level in maternal diet on the performance of low birthweight piglets.

	[a]Dietary treatments					[b]Contrasts	
	T13	T11	T9	T8	SEM	*L*	*Q*
Number of piglets, *n*	25	23	15	20			
Body measurements at birth, cm							
Crown-to-rump length	25.000	25.400	25.500	26.000	0.560	0.220	0.970
Body circumference	22.300	21.800	21.900	22.300	0.420	0.980	0.160
Body mass index, kg/m2	16.600	15.500	16.100	15.800	0.650	0.510	0.430
Ponderal index, kg/m^3	66.600	61.400	63.600	61.700	3.220	0.370	0.540
Body weight, kg							
At birth	1.040	1.010	1.040	1.060	0.047	0.640	0.460
5 d post-farrowing	1.610	1.590	1.580	1.540	0.095	0.530	0.860
16 d post-farrowing	3.940	3.780	3.590	3.850	0.287	0.700	0.390
Weaning	5.860	5.730	5.420	6.550	0.468	0.380	0.120
1 week post-weaning	5.920	5.960	5.560	6.950	0.498	0.200	0.120
2 week post-weaning	6.550	6.660	6.430	8.350	0.545	0.020	0.060
ADG, g/d							
Birth to 5 d post-farrowing	113	118	104	91	14.100	0.140	0.430
Birth to16 d post-farrowing	181	173	158	173	16.700	0.570	0.410
Birth to weaning	192	184	171	201	16.300	0.830	0.180
Weaning to 2 weeks post-weaning	50	62	74	113	27.000	0.090	0.560
1 week to 2 weeks post-weaning	91	103	125	187	27.000	0.010	0.250
Birth to 2 weeks post-weaning	141	143	135	177	11.500	0.040	0.050
Post-weaning diarrhoea,%							
1 week post-weaning	19.800	34.100	16.400	20.800	10.500	0.690	0.500
2 weeks post-weaning	36.400	16.700	6.500	5.200	8.310	<0.010	0.350
Days in diarrhoea, days							
1 week post-weaning	1.660	2.260	1.320	1.630	0.502	0.560	0.710
2 weeks post-weaning	2.360	1.220	0.550	0.870	0.512	<0.010	0.070

[a] T13 = Sow's lactation diet containing 13% of hemicelluloses; T11 = Sow's lactation diet containing 11% of hemicelluloses; T9 = Sow's lactation diet containing 9% of hemicelluloses; T8 = Sow's lactation diet containing 8% hemicellulose.
[b] Contrasts: *L*: Linear; *Q*: Quadratic.
ADG: average daily gain.

experimental treatments, whereas the copper content linearly increased ($p = .02$) with decreasing HC content in the maternal diet. Excluding the linear increase ($p = .04$) in the threonine level and the quadratic increase ($p = .04$) in the monounsaturated fatty acid portion, decreasing HC level in the maternal diet had no impact on the amino acid and fatty acid profiles. Regardless of the dietary treatments, somatic cell counts did not differ between the sampling days. However, the sampling day influenced protein, mineral and lactose contents, as well as milk yield. Between days 3 and 17 of lactation, protein, phosphorus, potassium and zinc contents decreased ($p \leq .05$), whereas lactose and calcium contents and milk yield increased ($p \leq .05$). Furthermore, histidine, leucine, isoleucine, phenylalanine, threonine, tryptophan, tyrosine, valine, alanine, aspartic acid and serine decreased ($p \leq .05$), whereas glutamate and proline increased ($p \leq .05$) between days 3 and 17. The fatty acid profile in milk changed during lactation. Monounsaturated and polyunsaturated fatty acid portions decreased ($p \leq .05$) and saturated fatty acid content increased ($p \leq .05$) from day 3 to day 17. More precisely, the portions of C18:0, C18:1$n - 9$, C18:2$n - 6$, C18:3$n - 6$, C18:3$n - 3$, C20:4$n - 6$, C20:5$n - 3$ and C22:5$n - 3$ decreased ($p \leq .05$), whereas C16:0 level increased ($p \leq .05$) between days 3 and 17.

Volatile fatty acid concentrations in milk

The VFA concentration and the proportion of butyrate linearly increased ($p < .01$; Table 5) with decreased HC content in the maternal diet, resulting in an increased in total VFA by 25% and butyrate proportion by 60%. Regardless of the dietary treatment, total VFA concentration decreased ($p \leq .05$) by 71% between days 3 and 17. The proportion of methanoate increased ($p < .01$), and the proportion of acetate decreased ($p < .01$) between days 3 and 17, whereas the levels of propionate, isobutyrate, butyrate and isovalerate remained unchanged.

Discussion

Effect of decreasing the level of hemicelluloses on sows' performance

In the present study, providing straw as enrichment was mandatory for the sow welfare. One cannot exclude that straw consumption may have attenuated the potential impact of the diets. Nevertheless, as the quantity of straw provided was the same for all the sows, a similar straw consumption may be assumed regardless of the dietary treatment. Excluding fibre intake, the sow's performances were not affected by dietary HC. In the present study, one goal was to have

Table 4. Effect of decreasing hemicellulose level in sow's lactation diet on gross composition, mineral content, amino acid profile and fatty acid profile of milk.

	[a]Dietary treatments					[b]Contrasts		[c]Stage of lactation			
Item	T13	T11	T9	T8	SEM	*L*	*Q*	d3	d17	SEM	*p*-value
Milk yield, kg/d	9.660	9.900	9.390	8.800	0.760	0.810	0.760	7.030	11.850	0.410	<.010
Gross chemical composition											
Dry matter, %	19.500	20.700	19.900	20.600	0.600	0.250	0.490	20.700	19.700	0.400	.060
Total protein, %	5.860	5.820	5.840	6.070	0.153	0.480	0.340	6.400	5.400	0.091	<.010
Fat, %	7.500	8.650	8.070	8.690	0.533	0.150	0.380	8.500	7.960	0.364	.270
Lactose, %	5.170	4.990	4.920	4.770	0.110	0.010	0.760	4.560	5.370	0.068	<.010
Ash,%	0.860	0.860	0.880	0.850	0.150	0.290	0.890	0.890	0.830	0.098	<.010
Somatic cells, log 103 cells/mL	6.990	6.920	7.400	7.710	0.325	0.180	0.410	7.400	7.110	0.248	.930
Gross energy, MJ/kg	5.140	5.700	5.430	5.700	0.230	0.100	0.300	5.650	5.340	0.162	.720
Minerals											
Calcium, g/kg	1.910	1.980	2.020	1.990	0.051	0.970	0.940	1.880	2.070	0.033	<.010
Phosphorus, g/kg	1.570	1.580	1.570	1.530	0.026	0.090	0.630	1.610	1.520	0.017	<.010
Potassium, g/kg	1.110	1.100	1.110	1.050	0.028	0.070	0.240	1.290	0.900	0.019	<.010
Sodium, g/kg	0.370	0.350	0.350	0.340	0.016	0.210	0.890	0.360	0.340	0.011	.930
Magnesium, g/kg	0.100	0.110	0.110	0.110	0.003	0.420	0.090	0.110	0.110	0.002	.570
Copper, mg/kg	1.370	1.450	1.510	1.760	0.135	0.020	0.280	1.680	1.370	0.085	.670
Zinc, mg/kg	6.040	6.640	6.020	5.440	0.363	0.160	0.070	6.380	5.690	0.213	<.010
Amino acids, % of total protein											
Alanine	3.280	3.290	3.330	3.350	0.025	0.210	0.460	3.410	3.210	0.017	<.010
Arginine	4.570	4.620	4.680	4.670	0.029	0.130	0.990	4.720	4.550	0.020	<.010
Aspartic acid	7.700	7.680	7.750	7.740	0.035	0.780	0.290	7.830	7.610	0.025	<.010
Cysteine	1.400	1.390	1.390	1.420	0.015	0.150	0.100	1.440	1.360	0.010	<.010
Glutamate	17.800	17.600	17.800	17.600	0.16	0.290	0.990	17.500	17.900	0.110	<.010
Glycine	2.980	3.020	3.120	3.050	0.030	0.100	0.400	3.060	3.030	0.019	.150
Histidine	2.530	2.530	2.530	2.560	0.015	0.850	0.310	2.560	2.510	0.009	<.010
Isoleucine	3.850	3.800	3.800	3.830	0.039	0.360	0.530	3.840	3.800	0.022	.050
Leucine	8.030	8.120	8.020	8.150	0.049	0.740	0.830	8.180	7.990	0.030	<.010
Lysine	6.860	6.790	6.820	6.860	0.049	0.610	0.360	6.850	6.820	0.029	.220
Methionine	1.740	1.720	1.710	1.710	0.014	0.100	0.680	1.720	1.720	0.008	.520
Phenylalanine	3.860	3.850	3.870	3.920	0.026	0.170	0.130	3.920	3.830	0.017	<.010
Proline	10.200	10.300	10.400	10.200	0.11	0.370	0.150	10.100	10.500	0.070	<.010
Serine	4.700	4.660	4.730	4.760	0.047	0.150	0.390	4.750	4.670	0.030	.020
Threonine	3.880	3.880	3.900	3.980	0.036	0.040	0.190	3.990	3.830	0.023	<.010
Tryptophan	1.180	1.180	1.210	1.200	0.017	0.170	0.940	1.230	1.150	0.011	<.010
Tyrosine	4.020	3.970	3.990	4.050	0.050	0.430	0.200	4.050	3.960	0.028	<.010
Valine	5.160	5.210	5.200	5.260	0.039	0.170	0.980	5.300	5.120	0.025	<.010
Fatty acids, % of total fatty acids											
C16:0	27.200	27.400	26.400	27.800	0.70	0.520	0.380	24.900	29.500	0.480	<.010
C18:0	4.290	4.430	4.330	4.410	0.143	0.700	0.700	4.780	3.950	0.089	<.010
C18:1$n-9$	35.300	36.100	35.800	34.800	0.83	0.510	0.380	37.200	33.800	0.570	<.010
C18:2$n-6$	11.450	9.630	12.080	11.740	0.412	0.090	0.090	12.200	10.300	0.245	<.010
C18:3$n-6$	0.140	0.120	0.150	0.130	0.012	0.930	0.870	0.200	0.080	0.008	<.010
C18:3$n-3$	1.080	1.120	1.160	1.320	0.057	0.060	0.530	1.250	1.090	0.036	<.010
C20:3$n-3$	0.110	0.110	0.110	0.090	0.010	0.760	0.480	0.110	0.100	0.006	.060
C20:4$n-6$	0.520	0.500	0.550	0.550	0.022	0.160	0.530	0.650	0.410	0.014	<.010
C20:5$n-3$	0.090	0.090	0.080	0.080	0.006	0.550	0.740	0.090	0.070	0.003	<.010
C22:5$n-3$	0.230	0.220	0.210	0.220	0.018	0.770	0.610	0.260	0.180	0.010	<.010
$n-3$[d]	1.750	1.590	1.500	1.480	0.082	0.190	0.600	1.720	1.440	0.051	<.010
$n-6$[e]	12.100	10.300	12.800	12.400	0.43	0.090	0.100	13.000	10.800	0.260	<.010
Saturated	36.100	36.400	35.300	37.100	0.76	0.570	0.400	33.800	38.600	0.520	<.010
Mono-unsaturated	49.100	50.800	49.500	48.100	0.61	0.710	0.040	50.400	48.300	0.420	<.010
Poly-unsaturated	14.800	12.800	15.200	14.900	0.53	0.220	0.140	15.700	13.100	0.320	<.010

[a] T13 = Sow's lactation diet containing 13% of hemicelluloses; T11 = Sow's lactation diet containing 11% of hemicelluloses; T9 = Sow's lactation diet containing 9% of hemicelluloses; T8 = Sow's lactation diet containing 8% of hemicelluloses.

[b] Contrasts: *L* = Linear; *Q* = Quadratic.

[c] Days: d3 = Day 3 of lactation; d17 = Day 17 of lactation.

[d] $n-3$: sum of C18:3$n-3$, C20:3$n-3$, C20:5$n-3$, C22:5$n-3$.

[e] $n-6$: sum of C18:2$n-6$, C18:3$n-6$ and C20:4$n-6$.

a similar total DF intake among the sows in the four treatments but different intakes of IDF and SDF. This objective was only partially achieved as there was no linear effect but a quadratic effect for total DF intake. Nonetheless, due to similar feed intake during the pre-farrowing and lactation periods, decreasing the level of HC also reduced the intake of the low-molecular-weight DF and SDF fractions. Similar to the present study, Shang et al. (2021) found no effect either on sow's BW or backfat thickness at farrowing and weaning when the dietary SDF level was decreased from 40.6 g/kg to 13.9 g/kg in the late gestation and from 27.2 g/kg to 14.3 g/kg during lactation. In addition, considerably high SDF intake can

Table 5. Effect of decreasing hemicellulose levels in sow's lactation diet on the volatile fatty acid profile of milk.

	[a]Dietary Treatments					[b]Contrasts		[c]Stage of lactation			
Item	T13	T11	T9	T8	SEM	*L*	*Q*	d3	d17	SEM	*p*-value
Total volatile fatty acids, mmol/kg	3.070	3.580	3.600	3.860	0.280	0.030	0.600	4.12	2.940	0.190	<.010
Proportion of individual VFA, %											
Methanoate	9.410	9.500	9.380	9.930	0.287	0.940	0.280	9.16	9.950	0.187	<.010
Acetate	88.900	89.000	88.900	88.300	0.353	0.310	0.170	89.21	88.360	0.220	<.010
Propionate	0.300	0.300	0.250	0.200	0.041	0.190	0.840	0.25	0.280	0.026	.290
Isobutyrate	0.040	0.040	0.050	0.030	0.007	0.860	0.790	0.04	0.050	0.004	.170
Butyrate	0.530	0.600	0.750	0.860	0.153	<0.010	0.640	0.68	0.690	0.104	.290
Isovalerate	0.760	0.550	0.570	0.570	0.080	0.800	0.210	0.61	0.610	0.043	.810

[a] T13 = Sow's lactation diet containing 13% of hemicelluloses; T11 = Sow's lactation diet containing 11% of hemicelluloses; T9 = Sow's lactation diet containing 9% of hemicelluloses; T8 = Sow's lactation diet containing 7% of hemicelluloses.
[b] Contrasts: *L*: Linear; *Q*: Quadratic.
[c] d3 = Day 3 of lactation; d17 = Day 17 of lactation.

negatively affect litter performance. Indeed, Liu et al. (2020) reported that from day 90 of gestation to farrowing, a daily intake of 215 g of SDF (SDF: 45.7 g/kg as fed), compared with 138 g/d (29.7 g/kg as fed) and 96 g/d (17.8 g/kg), decreases the number of piglets and litter weight at weaning. In the present study, sows received between 133 and 83 g/d of SDF according to the diets, from day 110 of gestation to farrowing. Therefore, compared to the study of Liu et al. (2020), the SDF intake during this period for the four treatment groups was not sufficiently elevated to negatively impact litter performances.

Effect of decreasing hemicelluloses levels on milk composition and milk VFA profile

Milk yield and composition play a crucial role in the growth of suckling piglets to reach an adequate weaning weight. In the present study, decreasing the level of HC in the maternal diet affected milk composition but did not affect milk yield. Furthermore, lactose content decreased, whereas copper and threonine proportions increased with decreased HC level. A previous study showed that glucose, glycerol and other glucose precursors play an important role in the synthesis of lactose in sow's milk (Boyd et al. 1995). Houdijk et al. (2002) reported that the fermentation of SDF occurs already at the end of the ileum. As decreasing the level of HC also decreased the intake of SDF, one can hypothesise that lowering the HC supply reduced the absorbed HC fermentation products available for lactose synthesis. Moreover, due to the osmotic power of lactose (Costa et al. 2019), milk yield may drop together with lactose as the HC level decreases. Surprisingly, milk yield only decreased numerically, and this result could be due to the differences in lactose concentration between the experimental groups, which were not sufficiently large to affect milk yield. A further interest in the present study is the linear increase in copper in milk with a decreased HC level. Copper is an essential microelement for animals, with many biological functions, including iron metabolism, immunity, protection from oxidative stress and improvement in the activity of digestive enzymes (Huang et al. 2015). The milk concentration of copper is affected by the source of the micromineral (Peters et al. 2010). However, as the same micromineral source was used among the four dietary treatments, the mechanism underlying the increase in copper concentration remains unclear. Similarly, with decreased HC levels in the diet, the proportion of threonine in the milk increased. This effect remains unclear, as the calculated digestible threonine levels were similar between the T13 and T8 diets. In addition, in the present study, a quadratic increase of mono-unsaturated fatty acid portion in milk was also observed as the HC level decreases, with the T11 sows exhibiting the greatest MUFA percentage in milk. It is well known that the fat level and the fatty acid composition in sow milk reflect the level and the sources of fat included in the sow's diet (Lauridsen and Danielsen 2004). As the fat source and the fat level in the dietary treatments were the same, no plausible explanation was found. Besides a similar DF content, hypothetically, decreasing the HC level using several DF sources may affect the fermentation patterns in the gut, namely, the concentration and proportion of VFA. As VFA can be absorbed, transported through the blood and finally reach the mammary glands, modifications in the milk composition are expected (Tian et al. 2020). A decrease in HC level increased total VFA concentration and butyrate proportion in milk. Zhao et al. (2019) showed a positive correlation between VFA concentration in pig's ileum and decreased HC level. Given that sows can ferment DFs better than growing pigs, a similar phenomenon may have occurred in the ileum of sows fed with a low HC level (Noblet and Le Goff 2001). Furthermore, this effect on VFA in milk may also be due to differences in the intake of other

DF fractions. As previously mentioned, decreasing HC level concomitantly increased ADF intake and decreased SDF intake. A positive correlation was reported between the ADF level in the pig's diet and butyrate concentration in the faeces (Zhao et al. 2019). In the present study, hypothetically, increased ADF intake in sows fed with decreasing level of HC might have increased the butyrate proportion in the faeces and then in the milk. Compared with IDF, SDF is rapidly fermented by bacteria, thereby enhancing the production of VFA (Jha and Berrocoso 2015). Therefore, with decreased SDF intake, VFA production should be lowered. However, the present study showed that this concept was not evident and confirmed the importance of the source of DF, as reported by some authors (Theil et al. 2014). Therefore, to understand the effects of DF on milk composition, different fractions of DF, including HC and ADF contents, must be considered.

Effects of the lactation diet on piglets' performance

In the present study, modifying the level of HC in the maternal diet did not enhance litter performance. This result is consistent with the results of Loisel et al. (2013), which showed that modifying the maternal diet is easier to positively affect the performances of L-BtW piglets than the performance of the litter overall. Therefore, decreasing the HC level improved post-weaning performance and reduced the occurrence of diarrhoea in the L-BtW piglets. By contrast, the reason for the quadratic effect observed on the occurrence and the number of days in diarrhoea in the second week post-weaning remains unknown. Nevertheless, these effects were not severe enough to affect the growth of the litter overall. In addition, the L-BtW piglets usually exhibit poor performances, such as a high mortality rate and low ADG, which represents high economic costs for farmers due to reduced slaughter weight and increased occupancy of the stables (López-Vergé et al. 2018). Previous studies highlighted the importance of early-life interventions to improve the post-weaning development and health of piglets and more particularly of this sub-population of piglets (Girard et al. 2020; Girard et al. 2021). In the present study, the beneficial effects observed in L-BtW piglets during the post-weaning period like the improved growth performance and the lower incidence of diarrhoea may be related to the combination of an increased relative abundance of butyrate, threonine and copper and to an increased concentration of total VFA in milk. Given that piglets are highly susceptible to intestinal bacterial disorders during the post-weaning period, butyrate, due to its recognised role in gut health, could have been useful in increasing gut impermeability, alleviating diarrhoea in L-BtW piglets during the second-week post-weaning (Feng et al. 2018). In addition, increasing threonine and copper proportions in the milk in the pre-weaning period can help accelerate the gut maturation of those piglets (Lalles et al. 2009). Threonine plays a critical role in the regulation of intestinal mucosal integrity, as it is required for the production of mucins and immunoglobulins, improving the physical protection from the attachment of microbes to the mucosal surface (Van Klinken et al. 1995). By contrast, copper can help against pathogenic bacteria because of its bacteriostatic properties, which affect the community structure of microorganisms in the caecum and colon (Højberg et al. 2005). A lower relative abundance of Alistipes, Lachnospiraceae, Ruminococcaceae and Prevotellaceae has been reported in the colon and ileum of L-BtW piglets compared with N-BtW piglets (Li et al. 2019). These genera enhance gut health and immune functions in the host (Den Besten et al. 2013). Given that, colostrum and mature milk are key components in shaping piglet microbiota (Trevisi et al. 2021), the modification of milk composition induced by decreased HC level in the sow diet might have changed the gut microbiota of L-BtW piglets and improved their health and growth.

Effect of lactation stage on milk composition

Sow's milk composition is strongly affected by changes throughout the lactation period. Transitional milk (48–72 h after parturition) contain higher amounts of lipids, protein and dry matter compared with mature milk (from day 10 of lactation) (Csapó et al. 1996). In the present study, the passage from transitional milk to mature milk was characterised by a decrease in protein and ash contents and an increase in lactose content. Nevertheless, the contents of fat, dry matter and gross energy decreased only numerically from day 3 to day 17. Indeed, in the present experiment, the lack of statistical differences on those traits is in disagreement with the study of Csapó et al. (1996), where differences between the sampling days were reported. This might be related to differences in sow genotypes, and litter size between the present study and the previous one. Different genotypes such as Danish Duroc, Danish Large White and Norwegian Landrace with an average litter size of 9.9 piglets were reported in the study of Csapó et al. (1996) whereas the present study was conducted on Swiss Large White sows with an average litter size of 11.5 piglets after cross-fostering. Similarly, the decrease in amino acid proportion follows the same trend as protein content, except for glycine, lysine and methionine, which remained stable over lactation, and for glutamate and proline, which increased from day 3 to day 17. Therefore, the high level of amino acids in transitional milk reflects the protein level, mainly because of the high content of immunoglobulins (Klobasa et al. 1987). The mineral content was also affected by the stage of lactation with an increase in the calcium level and a decrease in the potassium and zinc levels from transitional milk to mature milk in agreement with Csapó et al. (1996). Moreover, the phosphorus content decreased between days 3 and 17. The reason for this decrease over lactation remains unclear but might be related to a dilution effect, as it follows the numerical decrease in dry matter. When expressed per kilogram of dry matter, the phosphorus concentration was similar between days 3 and 17. Moreover, from transitional milk to mature milk, the decrease in the proportion of mono- and polyunsaturated fatty acids and the increase in the proportion of saturated fatty acids are related to changes in the proportion of individual fatty acids. The increase in C16:0 proportion and decrease in the proportions of C18:0, C18:1$n-9$, C18:2$n-6$, C18:3$n-6$, C18:3$n-3$, C20:4$n-6$ and C20:5$n-3$ observed in the present study have already been described in a previous study (Hu et al. 2019). Furthermore, Hu et al. (2019) reported a positive correlation between calcium and C16:0 fatty acid.

Conclusions

In conclusion, when the DF level is the same, feeding lactating sows with a lower HC level can positively affect the milk composition and the development of L-BtW piglets. As HC content decreased, the growth performance of the L-BtW piglets improved after weaning, and the occurrence of diarrhoea decreased, particularly in the second-week post-weaning. Moreover, it increased the proportion of butyrate, copper and threonine and increased the VFA concentration in the milk. The characterisation of DF components and their role during lactation may also have promising implications in shaping the offspring's microbiota, controlling the colonisation and the spread of pathogens, and reducing the risk of diseases. Furthermore, improving the development and health of L-BtW piglets in the post-weaning period through the maternal diet may offer an interesting approach to help these piglets to cope with their heavier litter mates in the post-weaning period and to homogenise litter weight. Whether these improvements have long-term effects deserve further investigation.

Acknowledgements

A preprint of this manuscript was deposited on agriRxiv (https://doi.org/10.31220/agriRxiv.2022.00116), and version 4 (R3) of the preprint has been peer-reviewed and recommended by Peer Community In Animal Science (https://doi.org/10.24072/pci.animsci.100014). The authors acknowledge Guy Maïkoff and all the barn technicians from the experimental piggery for taking care of the animals and for their help in sample collection. The authors also thank Sébastien Dubois, René Badertscher and Charlotte Egger and the laboratory technicians for the chemical analysis and for their valuable support.

Ethical approval

The experiment was conducted in accordance with the Swiss Guidelines for Animal Welfare, and the Swiss Cantonal Committee for Animal Care and Use approved all procedures involving animals (approval number: 2019_25_FR).

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work received no specific grant from any funding agency.

Data availability statement

The data that support the findings of this study are publicly available in Zenodo (https://doi.org/10.5281/zenodo.5814624).

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