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Pigs

Evaluating 20% and 40% Inclusion of Sugary Former Foods in Pig Diets: Effects on Growth Performance, Feeding Behaviour, Carcass and Meat Quality Traits

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ABSTRACT

Former food products (FFP) are food industry leftovers that can be used as feed ingredients. We investigated the effects of sugary FFP on growth, feeding behaviour, carcass and meat quality of pigs fattened to a heavy weight. Three inclusion levels were tested: 0% (FFP-0 = control), 20% (FFP-20) and 40% (FFP-40) FFP in grower (20–60 kg BW), finisher 1 (60–100 kg BW) and finisher 2 (100–140 kg BW) phase. A total of 36 castrated pigs were used, with 12 pigs within a litter assigned to each treatment, housed in a single pen equipped with automatic feeders that allowed recording of individual (*ad libitum*) feed intake at each visit. The pigs were slaughtered in two batches at the age of 190.9 ± 1.5 days and BW of 144.7 ± 8.8 kg. At slaughter, carcass weight, *longissimus dorsi* (LD) pH and carcass traits were measured. The following day, body composition of carcasses was determined using dual-energy X-ray absorptiometry and then carcasses were dissected into primal cuts, and meat quality was assessed. Data were analysed with SASV9.4 (PROC MIXED), with diet as a fixed effect and litter (dam) as a random effect in the model. Linear effects of sugary FFP inclusion were tested. In the grower period, daily feed intake and daily gain decreased with increasing sugary FFP inclusion. In finisher periods, a tendency towards lower daily feed intake was observed with increasing sugary FFP inclusion, which did not affect daily gain, but led to better feed conversion in the finisher II period. In the grower period, no differences in feeding behaviour were observed, while in finisher II period, FFP-20 pigs spent the shortest time at the feeder, consumed more feed per minute, had a longer interval between visits, but tended to go to the feeder more often than the FFP-0 or FFP-40 pigs. Compared to control, the sugary FFP inclusion was associated with increased carcass protein and water and decreased fat content, in line with thinner backfat. The decrease in ultimate pH and CIE (Commission Internationale d'Eclairage) colour parameter L* of LD were the only significant effects on meat quality. The backfat fatty acid composition was affected by sugary FFP inclusion (more monounsaturated fatty acids and less polyunsaturated fatty acids with higher Σn6:Σn3 ratio). In summary, the sugary FFP inclusion of up to 40% had a limited effect on growth performance and meat quality but resulted in less deposition of fat and altered adipose tissue fatty acids profile.

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1 | Implications

In the search for sustainable pig diets, incorporating food leftovers offers a viable alternative to traditional cereal-based feeds. This study demonstrated that including 40% sugary food leftovers in pig diets during the early growth phase may be a limit, as it led to reduced feed intake (FI) and growth rate. However, no adverse effects were observed in the later production stages, and overall performance remained unaffected. These findings support the use of sugary former foods in heavy pig production to reduce feed-food competition. However, they are specific to the tested sugary FFP and should not be generally extrapolated to other FFP sources.

2 | Introduction

The global demand for protein is projected to rise as the world population continues to grow, which will intensify the competition between the use of crops for animal feed and direct human consumption, often referred to as "feed-food competition" (AgriResearch 2019). This issue is expected to particularly impact pig farming, as it heavily relies on feed crops like cereal grains and soybean, making it more susceptible to land use and resource allocation priorities. The European Commission's Green Deal strategy (EC 2019) envisions a transition to agroecological food systems that must be designed in a more holistic manner to best balance the demands for productivity, sustainability, quality, and other societal values. Minimising food waste is one of the pathways towards sustainable development goals (FAO 2018) and sustainable food systems and an important challenge for transition to agroecological food systems (Sachet et al. 2021). Although the use of food waste for animal nutrition is restricted in the EU, there are some exceptions (Commission Regulation 68 2013) such as leftovers from the food industry (e.g., biscuits, bread, pasta, sweets, snacks), known as former food products (FFP). Due to their nutritional properties, e.g., high energy and low protein content FFP are considered as potential substitutes for cereals in pig diets (Giromini et al. 2017). Recent studies have shown that incorporating up to 30% of FFP into the diet of finishing pigs raised to the typical market weight (100–110 kg) did not adversely affect growth rates or body composition (Mazzoleni et al. 2023), while the effects were noted for fatty acid profile of pork and sensory quality of the loins (Tretola et al. 2024). Namely, both salty and sugary FFP increased the Σn6:Σn3 polyunsaturated fatty acids ratio and improved some sensory properties (Tretola et al. 2024). The question remains, however, to what extent can FFP be incorporated into pig diets without adverse effects. Furthermore, incorporating FFP as ingredients to mitigate feed-food competition could be particularly relevant in heavy pig production (practice of rearing pigs to higher slaughter weights and ages than standard commercial pigs) aimed at high-value meat products. This production system involves extended fattening periods, higher feeding costs, while also demanding raw material of specific quality to meet the requirements of traditional cured meat products. Therefore, evaluating the use of FFP in the pig diets is particularly relevant for this type of production system. To the best of our knowledge, there is a lack of data on how a diet high in FFP would affect the performance and quality of fat and muscle tissue in pigs undergoing prolonged heavy weight fattening. Pigs metabolise nutrients differently depending on the composition of the feed (Le Goff and Noblet 2001) which can lead to variations in fat deposition, muscle growth or energy utilisation. In addition, due to the high glycemic index and fat content of sugary FFP (Ottoboni et al. 2019), their inclusion in pig diets could impact their digestion and metabolism. Changes in the composition of the diet could also influence feeding behaviour, such as the frequency and duration of meals, as pigs can adjust their FI according to nutrient density and taste of the diet (Ferguson et al. 1999; Pichler et al. 2020). Understanding these effects is crucial for optimising the proportion of FFP in pig diets and minimising any potential adverse impacts. As the 30% inclusion level demonstrated no adverse effects (Mazzoleni et al. 2023), this outcome suggests that even higher inclusion levels can be envisaged. Furthermore, investigating whether a linear dose-response relationship exists would be valuable in determining the optimal inclusion level. Therefore, the proposed study aimed to evaluate the effects of diets containing different amounts of sugary FFP, namely 20% and 40% inclusion, on feeding behaviour, growth performance, carcass composition and pork quality. In addition, the effects were investigated in heavier pigs subjected to a longer fattening period than those typically used in standard production systems.

3 | Materials and Methods

The protocol for this experiment was set in accordance with Swiss guidelines for animal welfare and received authorisation (2021-35-FR) from the Swiss Federal Committee for Animal Care and Use (Canton Fribourg-Switzerland). The study was conducted at the Agroscope Experimental Swine Research Centre in Posieux (Fribourg, Switzerland).

3.1 | Animals, Diets and Slaughtering Procedure

Thirty-six Swiss Large White castrated male piglets originating from six litters were used in this study. At the start of the grower period (~20 kg body weight [BW]), pigs were assigned within litters to three experimental diets: 0% FFP (FFP-0), 20% (FFP-20) and 40% (FFP-40). To formulate the diets, sugary FFP containing products such as chocolate, breakfast cereals, and cookies were used. The sugary FFP used to formulate experimental diets was produced by LANDI (Sursee, Switzerland) and its composition can be found in Supporting Information S1: Table S1. The FFP-0 grower, finisher I and finisher II diets were formulated based on the Swiss feeding recommendations for pigs (Agroscope, 2022, Table 1) using a reference BW of 40, 80 and 120 kg, respectively. For the FFP-20 and FFP-40 grower and finisher diets, a part of the cereals and fats contained within in the respective FFP-0 diets were substituted by the sugary FFP. Care was taken that regardless of the treatment, the grower and finisher diets were isoenergetic and isonitrogenous. All diets included microbial phytase at 500 FTU/kg (0.16 digestible P/100 FTU) and the Ca-to-digestible P ratio was fixed at 2:8:1 and were prepared as pellets (< 70°C).

Pigs were housed in a single-group pen fitted with three computerised feeders (one per treatment group) designed for individual access (Mastleistungsprüfung MLP-RAP; Schauer Agrotronic AG,

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TABLE 1 | Dietary ingredients and analysed nutrient content of the grower, finisher I and finisher II diets with sugary former foods products (FFP).

	Dietary treatments[a]								
	Grower			Finisher I			Finisher II		
	FFP-0	FFP-20	FFP-40	FFP-0	FFP-20	FFP-40	FFP-0	FFP-20	FFP-40
Ingredients[b]									
FFP		20.00	40.00		20.00	40.00		20.00	40.00
Barley	30.20	18.00	7.30	18.46	14.24	4.28	6.37	6.38	1.00
Wheat	40.00	20.00		40.00	20.00		40	20	
Wheat starch		8.25	10.00	9.85	9.96	12.97			
Whole corn plant (dehydrated)							15.00	15.00	15.00
Oat							10.00	2.96	
Soy extraction meal	10.65	13.23	15.46	8.32	9.70	11.13	1.31	2.69	7.10
Rapeseed pressure meal							6.56	6.86	
Sugar beet pulp	3.43	3.64	10.00	10.00	10.00	7.00	10.00	10.00	8.60
Blended fat	3.00	1.21		1.87	0.60		1.29		
Wheat bran	7.15	10.31	12.1	2.95	7.02	16.29		4.85	17.07
Sugar beet molasses				3.90	4.00	4.00	2.00	4.00	4.00
Apple pomace							5.00	5.00	5.00
L-Lysine-HCl	0.36	0.30	0.26	0.22	0.20	0.29	0.26	0.24	0.36
DL-Methionine	0.07	0.07	0.02	0.02	0.02	0.01	0.02	0.03	0.07
L-Threonine	0.11	0.12	0.08	0.07	0.07	0.10	0.09	0.10	0.11
L-Tryptophan			0.06	0.06	0.06	0.01	0.01	0.01	
L-Valine	0.36	0.30	0.26	0.22	0.20	0.29	0.26	0.24	0.36
MCP	0.45	0.45	0.50	0.28	0.24	0.15	0.12	0.07	
Calcium carbonate	1.27	1.22	1.09	0.82	0.80	0.86	0.77	0.75	0.87
Sodium chloride	0.48	0.38	0.30	0.39	0.29	0.19	0.46	0.34	0.25
Pellan	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Celite	2.00	2.00	2.00	2.00	2.00	2.00			
Mineral-vitamin premix	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Microbial phytase	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Analysed nutrient and gross energy content[c]									
Dry matter, g/kg	895	904	912	897	903	916	900	905	912
Crude ash, g/kg	66	68	73	60	63	67	44	47	50
Crude fibre, g/kg	43	46	48	46	47	51	85	86	78
Crude fat, g/kg	47	57	68	36	53	76	39	53	81
Crude protein, g/kg	156	163	158	139	135	139	127	126	125
Water soluble carbohydrates, g/kg	39.3	96.7	149.3	76	119.5	170.3	61.9	109.7	163.7
Starch, g/kg	476.0	377.9	231.6	482.3	364.0	242.1	411.3	286.8	159.6
Lysine	8.9 [8.30]	9.5 [8.30]	9.1 [8.3]	6.9 [6.24]	6.9 [6.24]	7.3 [6.24]	6.7 [5.49]	6.8 [5.49]	7.0 [5.49]
Methionine + cysteine	5.4 [4.90]	5.5 [4.79]	5.0 [4.65]	4.3 [3.86]	4.3 [3.76]	4.3 [3.69]	4.8 [3.54]	4.4 [3.39]	4.0 [3.21]
Threonine	5.7 [4.76]	6.1 [4.76]	6.2 [4.91]	4.8 [3.72]	4.8 [3.72]	5.0 [3.72]	4.9 [3.35]	5.0 [3.35]	5.0 [3.36]
Tryptophan	1.9 [1.40]	2.1 [1.40]	2.0 [1.40]	2.1 [1.72]	2.1 [1.72]	2.1 [1.72]	1.6 [1.01]	1.6 [1.00]	1.6 [1.02]
Valine	7.0 [5.82]	7.6 [5.80]	7.6 [5.82]	6.4 [4.96]	6.3 [4.96]	6.6 [4.96]	5.6 [3.67]	5.7 [3.60]	5.8 [3.65]
Leucine	9.9 [8.45]	10.8 [8.75]	10.5 [9.01]	8.9 [7.17]	8.6 [7.34]	8.9 [7.53]	8.6 [5.89]	8.5 [6.01]	8.6 [6.30]
Isoleucine	5.5 [4.35]	6.1 [4.49]	6.2 [4.60]	5.1 [3.71]	4.9 [3.75]	5.2 [3.79]	4.5 [2.90]	5.4 [2.90]	4.7 [3.02]
Phenylalanine	6.7 [5.65]	7.2 [5.65]	6.9 [5.61]	6.0 [4.70]	5.7 [4.66]	5.7 [4.57]	5.4 [3.65]	5.2 [3.53]	5.3 [3.62]
Histidine	3.3 [2.82]	3.5 [2.82]	3.5 [2.82]	3.0 [2.40]	2.9 [2.35]	3.1 [2.32]	2.8 [1.98]	2.8 [1.91]	3.0 [1.86]
Tyrosine	4.6 [4.76]	5.1 [4.77]	5.0 [4.91]	4.1 [3.72]	4.0 [3.72]	4.1 [3.72]	3.8 [3.35]	3.8 [3.35]	3.9 [3.36]
Total fatty acids	46.93	58.48	77.58	38.77	56.01	76.60	44.31	56.71	81.04

(Continues)

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TABLE 1 | (Continued)

	Dietary treatments[a]								
	Grower			Finisher I			Finisher II		
	FFP-0	FFP-20	FFP-40	FFP-0	FFP-20	FFP-40	FFP-0	FFP-20	FFP-40
Fatty acid composition, g/100 g fat									
C10:0		0.18	0.12		0.26	0.47		0.25	0.51
C12:0	0.15	0.85	1.17	0.18	2.78	4.23	0.10	2.75	4.05
C14:0	1.35	1.57	1.77	1.21	3.22	4.22	0.87	2.94	4.02
C15:0	0.26	0.21	0.19	0.27	0.29	0.30	0.19	0.24	0.28
C16:0	22.53	20.86	19.87	22.21	23.08	23.27	18.21	20.16	22.66
C17:0	0.61	0.36	0.23	0.54	0.34	0.29	0.37	0.24	0.28
C18:0	10.59	13.61	15.05	8.74	13.46	15.64	6.23	11.42	15.51
C20:0	0.16	0.40	0.46	0.18	0.36	0.15	0.24	0.41	0.46
SFA	35.80	38.16	38.87	33.33	43.78	48.83	26.22	38.41	47.85
C14:1n-5	0.19	0.14	0.12	0.18	0.21	0.23	0.16	0.16	0.22
C16:1n-7	1.54	0.81	0.46	1.43	0.74	0.54	1.07	0.53	0.54
C17:1n-7	0.36	0.19	0.10	0.35	0.16	0.11	0.25	0.14	0.11
C18:1n-7	2.31	1.60	1.24	2.44	1.62	1.32	2.94	1.92	1.16
C18:1n-9	27.87	32.85	38.15	27.21	27.78	29.99	32.34	32.33	29.89
C20:1n-9	0.45	0.31	0.21	0.37	0.23	0.15	0.46	0.25	0.14
MUFA	32.71	35.90	40.28	31.99	31.74	32.34	37.23	35.32	32.06
C18:2n-6	26.70	25.56	18.76	30.88	21.77	16.61	32.79	23.45	17.64
C18:3n-3	2.12	1.83	1.48	2.21	1.61	1.27	2.87	2.14	1.53
C20:2n-6	0.15	0.13		0.14					
PUFA	29.12	24.61	20.28	14.07	13.54	13.04	35.66	25.59	19.17
Σn-6:Σn-3 PUFA ratio	12.65	12.36	12.72	14.07	13.54	13.04	11.41	10.94	11.56
Σ(SFA + MUFA):ΣSFA	2.64	2.52	2.59	2.91	1.98	1.69	4.20	2.50	1.74
C18:1n-7:C18:0	2.63	2.41	2.53	3.11	2.14	1.92	5.20	2.83	1.93
Digestible energy, MJ/kg	13.7	13.7	13.7	13.7	13.7	13.7	12.8	12.8	12.8
Net energy, MJ/kg	10.1	10.0	9.7	10.1	9.9	9.8	8.9	8.7	8.7

[a]The grower, finisher I and finisher II diets were formulated for pigs with a body weight (BW) of 40, 80 and 120 kg, respectively. FFP-0 = standard diet without sugary former foodstuff product (FFP) inclusion; FFP-20 = in the diets a part of the cereals was replaced with 20% sugary FFP; FFP-40 = in the diets a part of the cereals was replaced with 40% sugary FFP.
[b]MCP = monocalcium phosphate; FFP = pure sugary former foodstuff products; Pellan = binder that aids in pellet formation; mineral-vitamin premix supplied the following nutrients per kg of diet: 20,000 IU vitamin A, 200 IU vitamin D_3, 39 IU vitamin E, 2.9 mg riboflavin, 2.4 mg vitamin B_6, 0.010 mg vitamin B_{12}, 0.2 mg vitamin K_3, 10 mg pantothenic acid, 1.4 mg niacin, 0.48 mg folic acid, 199 g choline, 0.052 mg biotin, 52 mg Fe as $FeSO_4$, 0.16 mg I as $Ca(IO)_3$, 0.15 mg Se as Na_2Se, 5.5 mg Cu as $CuSO_4$, 81 mg Zn as ZnO_2, and 15 mg Mn as MnO2. Natuphos 5000 G = a feed enzyme combination that includes 3-phytase, beta-xylanase and beta-gluconase.
[c]Values in brackets represent the values of ileal digestible amino acids obtained from the Allix software and are calculated from the relative amount of each ingredient in the six diets; MUFA = monounsaturated fatty acid; PUFA = polyunsaturated fatty acids; SFA = saturated fatty acids.

Sursee, Switzerland), enabling to record FI and feeding behaviour on the individual basis. As the treatment was applied at the individual level (e.g., via automatic feeders), each animal was considered the experimental unit, consistent with the scientific opinion of De Cuyper et al. (2025). The pigs were provided with unrestricted access to fresh water and to the grower (20–60 kg BW), finisher I (60–100 kg BW) and finisher II (100 kg BW to slaughter) diets. The BW of all animals was recorded on a weekly basis. The total feed intake (FI), average daily gain (ADG), average daily feed intake (ADFI), feed efficiency was assessed as feed conversion ratio (FCR) for the growing and the two finishing phases. The pigs were kept on the diet until they attained targeted slaughter BW (~140 kg), and then, they were slaughtered at the Agroscope research slaughterhouse after fasting for 16 h. The animals were stunned with CO_2, after which they were exsanguinated, scalded, mechanically dehaired, and eviscerated. The carcasses were sectioned in two sides according to Swiss standard (including head, feet, tail and flare fat). Thirty minutes after exsanguination, hot carcass weights were recorded, and next, the carcasses were chilled at 2°C for 24 h.

3.2 | Feeding Behaviour

The automatic feeders recorded all daily visits to the feeder, FI per visit, and time spent at the feeder. Feeding behaviour was analysed on a daily basis rather than at the level of individual meals (Carcò et al. 2018). As proposed by de Haer and Merks 1992, feeder visits occurring within a 5-min interval were grouped together and considered as a single meal. Data on total time spent feeding per day (expressed in minutes), number of daily meals, time spent at the feeder per visit (expressed in minutes), FI per visit (expressed in g), rate of FI (expressed in g per minute) and the interval between two meals (expressed in minutes).

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3.3 | Carcass Traits and Composition With Dual-Energy X-Ray Absorptiometry (DXA)

One day postmortem, the left-side cold carcass (with head) was weighed and then scanned using a DXA (Lunar i-DXA, GE Healthcare Switzerland, Glattbrugg, Switzerland). The calibration of device passed the verification before each session by scanning a calibration phantom in accordance with the manufacturer's instructions. The scan was carried out using the "Total body—thick" acquisition mode with enCORE software (version 18). The obtained images were processed to define a single region of interest for the complete half carcass which was the "right arm". Then two regions of interest were defined as the total half carcass and the head. Data for total mass, lean tissue mass, fat tissue mass and bone mineral content were exported from the software. Subsequently, the left carcass side was dissected, and the primal cuts were weighed as described by Bee (2002). The carcass yield, expressed as the proportion of the hot carcass weight over the BW at slaughter, was also assessed. Carcass traits were assessed using fatness and muscularity proxies as described by Batorek et al. (2012). Fatness proxies were fat thickness on the carcass split line (at withers, last rib, over *m. gluteus medius*) and fat area over the loin eye at the level of last rib. For muscularity proxies, loin eye area at the level of last rib and muscle depth M (as the shortest distance between the dorsal edge of vertebral channel and cranial edge of *m. gluteus medius*) were measured.

3.4 | Meat Quality

Meat quality traits were assessed as described by Batorek et al. (2012). The pH was measured 15 min and 24 h post-mortem in LD at the level of last rib (using Testo 205 pH meter, Testo SE & Co, KGaA, Lenzkirch, Germany). After pig carcasses were cooled overnight at 0°C–2°C, they were cut at the level of last rib perpendicularly to the spine. On the freshly cut surface, marbling (on a scale 1–7) and subjective colour (scale 1–6) were evaluated, and objective colour parameters were measured with Minolta chromameter (CIE L*, a*, b*). For drip loss (EEZ method) assessment, cylindrical samples of LD approximately 10 g were excised, weighted and stored for 48 h at 4°C, when they were reweighed. Drip loss was expressed as the proportion (%) of sample weight loss over the initial weight.

3.5 | Chemical Analysis

Dry matter of feed mixtures was determined gravimetrically after drying at 105°C for 3 h. Ash content was measured after incineration for 3 h at 550°C. The crude protein (CP) content (total N × 6.25) was analysed with a LECO FP-2000 analyzer (Leco, Mönchengladbach, Germany; International Organisation for Sterk et al. 2008). Amino acids in the feed were determined according to ISO 13903:2005; in brief, following the oxidation, feed samples were submitted to 24-h acid hydrolysis with 6 M HCl and derivatized with AccQ-Tag Ultra reagent (Waters, Milford, MA, USA). Content of amino acids was determined with ultra-high-performance liquid chromatography coupled with a UV detector (Vanquish Horizon, Thermo Scientific, Reinach, Switzerland). To determine the crude fat content in the feed, samples were hydrolysed in 10% (v/v) HCl for 1 h. The resulting hydrolysate was then dried and extracted with petroleum ether using a Büchi SpeedExtractor E 916 (Büchi Labortechnik AG, Flawil, Switzerland). Crude fibre content was obtained gravimetrically (ISO 6865:2000) by incinerating residual ash folowing acid and alkaline digestions in a fibre analyzer (Fibretherm Gerhardt FT-12, C. Gerhardt GmbH & Co. KG, Königswinter, Germany). The fatty acid profiles of the feed were analysed using lyophilised samples according to Ampuero Ampuero et al. (2014). In brief, lipids were transmethylated for 3 h at 70°C with 5% methanolic HCl. Fatty acids methyl esters were neutralised with a potassium carbonate solution, purified on a silica gel and analysed by gas chromatograph (6850 series; Agilent Technologies AG, Basel, Switzerland) equipped with a flame ionisation detector (detector temperature 250°C). Nonadecanoic acid methyl ester (19:0) was used as internal standard. Fatty acids in the backfat were also determined by transmethylation/esterification under acid catalysis (5% HCl in MeOH) at 70°C for 3 h according to Ampuero Kragten et al. (2014). In brief, depending on their fat content, the samples were added 0.25–2 mL of internal standard (C 19:0; nonadecanoic acid), 3–6 mL of HCl (5% in methanol), and between 0 and 1.75 mL of toluene. The reaction mixture was brought to neutralitywith 6% K_2CO_3 and purified by solid-phase extraction. Fatty acids were determine with a gas chromatograph equipped with a flame ionisation detector and a Supelcowax 10 polar column of 15 m × 0.1 mm, 0.1 μm of length (Agilent 6850, Agilent Technologies, Switzerland).

3.6 | Calculations and Statistical Analysis

The lean tissue mass, fat tissue mass and bone mineral content of the carcass was calculated as the respective values times left carcass minus head time 2, plus head. The chemical contents (water, protein, fat, ash) and gross energy contents of the carcass were calculated from the DXA values according to Kasper et al. (2021). To estimate the daily rate of ash, fat, protein and energy deposition in the carcass, the nutrient composition of pig carcasses at 20 kg BW was predicted using data from Ruiz-Ascacibar et al. (2017). The nutrient and energy values reported in the study by Ruiz-Ascacibar et al. (2017) were expressed per kg BW and then multiplied by the BW of the current pigs at the beginning of this experiment. The estimated amount of protein and gross energy deposited in the carcasses divided by the amount of protein, gross, digestible and net energy ingested was used to calculate protein and energy deposition efficiency.

Data were analysed using the MIXED procedure of SAS software (Version 9.4, SAS Institute, Cary, NC, USA). The model included dietary treatments as the fixed effect and litter (dam) as the random effect to account for the non-independence of piglets from the same sow and to adjust for shared maternal and early-life influences (gestation and lactation environment, and shared genetics) on the traits of interest. Orthogonal contrasts were performed for the linear effects of the increasing dietary levels of FFP. Contrasts were not considered unless the overall model was significant ($p \leq 0.05$) or tended to be significant ($0.05 < p \leq 0.10$). Least square means were calculated and considered statistically significant at $p < 0.05$. In addition to assessing the likelihood that treatment effect is not due to

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chance, effect size helps the reader understand the magnitude of the observed differences; both are essential for interpreting the importance of the treatment (Sullivan and Feinn 2012). Therefore Hedges' g values were calculated (Hedges and Olkin 1985) for pairwise comparisons between treatment groups to compare the magnitude of the differences between treatment groups as the small-sample bias–corrected standardised mean difference:

$$g = \mathrm{J} \times \frac{\bar{\mathrm{x}}_A - \bar{\mathrm{x}}_B}{Sp}$$

where $\bar{\mathrm{x}}_A$ and $\bar{\mathrm{x}}_B$ are the sample means of compared groups, Sp is the pooled standard deviation of compared groups, J is a correction factor (0.9655 for $n = 12$). As a guide: $|g| \approx 0.2$ denotes small, ≈ 0.5 medium, > 0.8 large effects.

4 | Results

The primary objective while formulating the grower, finisher I, and finisher II diets was to ensure they were isocaloric and that they provided similar levels of digestible essential amino acids. This was achieved by replacing wheat with FFP and adjusting the amount of cereals to compensate for the increasing levels of FFP (Table 1). In the formulation of diets, the care was taken to incorporate or reduce raw materials as linearly as possible while maintaining similar nutrient levels (digestible energy, digestible amino acids, protein and fibre) but multiple constraints that needed to be respected made diet formulation quite challenging. With higher inclusion level of FFP in the diet, dietary sugar and lipid contents increased, starch content decreased, while crude fibre levels remained relatively unchanged (Supporting Information S1: Figure S1). No consideration was given to the impact of FFP inclusion on dietary fatty acid composition. As a result, the inclusion of FFP led to an increase in both saturated (SFA) and monounsaturated fatty acids (MUFA), with a more pronounced effect on MUFA levels. This increase in MUFA was primarily due to a rise in oleic acid (C18:1n-9). Additionally, increasing levels of FFP were associated with decreasing levels of linoleic acid (C18:2n-6) and alpha-linolenic acid (C18:3n-3) and ultimately also of total polyunsaturated fatty acids (PUFA).

4.1 | Growth Performance

In accordance with the experimental design, initial BW and BW at slaughter were similar among pigs across the three diets (Table 2). The BW at transition from grower to finisher I and from finisher I to finisher II diets were also similar between groups. However, the day before slaughter the BW tended to linearly ($p = 0.064$) decrease with increasing FFP inclusion (in line also with effect size of 0.5 between FFP-0 and FFP-40, i.e., a medium effect). During the grower period, ADG decreased with increasing FFP levels, indicating a negative linear trend (linear; $p < 0.001$). However, during the finisher I and II periods and the total period, there was no difference in ADG between the dietary treatments. On the other hand, ADFI decreased with increasing FFP inclusion into the diet (linear; $p < 0.001$) during the grower period, in line with the decreasing ADG. Similarly, overall ADFI and total FI decreased with increasing FFP inclusion (linear; $p \leq 0.001$). During the grower and finisher I periods, feed efficiency did not differ between treatment groups. However, during the finisher II period and the overall period, feed efficiency improved with higher FFP contents, showing a significant linear trend (linear; $p < 0.001$). Overall, feed efficiency was also improved with higher FFP inclusion levels (linear; $p < 0.001$). The number of days on feed during the grower and finisher I periods did not differ between treatments. However, the finisher II period of FFP-20 and FFP-40 pigs was 2.3 and 8.1 days shorter than that of FFP-0 pigs (linear $p = 0.004$).

4.2 | Feeding Behaviour

During the grower and finisher II phases, no statistically significant differences in feeding behaviour were observed between the treatment groups, while some differences were observed in finisher I phase (Table 3). Time spent at feeder, FI per visit and rate of FI was affected by diet, but not linearly. On the other hand, FI per visit showed a linear ($p = 0.043$) decreasing effect. Similar trend was also observed in grower ($p = 0.129$) and finisher II ($p = 0.087$) phase, although not statistically significant. It should, however, be noted that although the effects were observed mainly as statistical tendencies, the corresponding effect sizes were medium to large, indicating a non-negligible treatment impact.

4.3 | Carcass Traits and Composition (by DXA)

As described above, the nutrient and gross energy content of the pigs was estimated at the beginning of the trial based on a fixed relationship previously determined for a pig of 20 kg BW. At the start of the experiment, carcass weight, water, ash, fat, protein and gross energy contents were similar across the three dietary treatments (Table 4). At slaughter, carcass weight, ash, fat and energy content decreased with increasing dietary FFP level (linear; $p \leq 0.006$), whereas water and protein content were not affected by the dietary treatments. When expressed as a percentage of carcass weight, relative water and protein content increased with increasing levels of FFP inclusion (linear; $p = 0.005$), and both relative fat and energy content decreased (linear; $p = 0.002$).

There was a linear decrease in the daily deposition rate of ash, fat and gross energy with higher FFP levels (linear; $p \leq 0.021$) whereas protein deposition rate was unaffected by the dietary treatments. By contract, protein deposition efficiency increased linearly with higher dietary FFP levels (linear; $p = 0.002$). Energy efficiency based on gross energy intake decreased from the FFP-0 to the FFP-40 treatment (linear; $p = 0.003$). However, energy efficiency based on net energy intake, but not on digestible energy intake, tended ($p = 0.075$) to be affected by the dietary treatment, increasing linearly as FFP content increased (linear; $p = 0.036$).

Consistent with data on growth performance and body composition (measured by DXA), both hot carcass weight and yield (linear; $p \leq 0.002$) declined with increasing levels of FFP inclusion in the diet (Table 5). Along with a reduction in carcass weight, indicators of carcass muscularity such as ham and

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TABLE 2 | Growth performance of pigs fed grower and finisher diets supplemented with increasing levels of sugary former food products (FFP).

	Dietary treatments[a]				*p*-value[b]		Effect size[c]		
	FFP-0 (1)	FFP-20 (2)	FFP-40 (3)	SEM	Diet	Linear	1–2	1–3	2–3
Body weight (kg) at									
Start	23.01	22.06	22.77	0.464	0.334	0.715	0.6	0.1	−0.4
End of grower period	65.72	64.57	64.12	0.789	0.347	0.161	0.4	0.6	0.2
End of finisher I period	104.55	104.03	103.70	0.853	0.778	0.486	0.2	0.3	0.1
End of finisher II period	147.74	145.54	142.12	2.902	0.170	0.064	0.2	0.5	0.3
Average daily gain, kg/d									
Grower period	0.863	0.829	0.761	0.0190	< 0.001	< 0.001	0.5	1.5	1.0
Finisher I period	1.118	1.170	1.088	0.0325	0.162	0.476	−0.4	0.3	0.7
Finisher II period	0.923	0.917	0.975	0.0387	0.487	0.328	0.0	−0.4	−0.4
Overall	0.947	0.945	0.916	0.0185	0.285	0.159	0.0	0.5	0.4
Total feed intake, kg									
Grower period	96.76	92.44	91.00	2.603	0.223	0.098	0.5	0.6	0.2
Finisher I period	111.18	108.79	111.01	2.590	0.768	0.962	0.3	0.0	−0.2
Finisher II period	165.81	153.66	131.87	9.289	0.004	0.001	0.4	1.0	0.7
Overall	374.61	355.75	334.73	9.163	< 0.001	< 0.001	0.6	1.2	0.6
Average daily feed intake, kg/d									
Grower period	1.947	1.798	1.676	0.0315	< 0.001	< 0.001	1.3	2.4	1.1
Finisher I period	3.191	3.196	3.049	0.0834	0.170	0.110	0.0	0.5	0.5
Finisher II period	3.541	3.411	3.380	0.0887	0.225	0.105	0.4	0.5	0.1
Overall	2.841	2.718	2.565	0.0578	< 0.001	< 0.001	0.6	1.3	0.7
Feed efficiency, kg feed/kg gain									
Grower period	2.264	2.176	2.211	0.0407	0.187	0.269	0.6	0.4	−0.2
Finisher I period	2.856	2.736	2.820	0.0609	0.293	0.648	0.5	0.2	−0.4
Finisher II period	3.851	3.759	3.487	0.0898	0.020	< 0.001	0.3	1.1	0.8
Overall	2.999	2.874	2.803	0.0347	< 0.001	< 0.001	1.0	1.6	0.6
Days on feed, d									
Grower period	49.6	51.3	54.3	1.49	0.096	0.033	−0.3	−0.9	−0.6
Finisher I period	35.0	34.4	36.8	1.19	0.349	0.296	0.1	−0.4	−0.6
Finisher II period	46.9	44.6	38.8	2.57	0.011	0.004	0.2	0.9	0.6

[a]FFP-0 = grower, finisher I and finisher II diets with 0% sugary FFP inclusion; FFP-20 = grower, finisher I and finisher II diets with 20% sugary FFP; FFP-40 = grower, finisher I and finisher II diets with 40% sugary FFP.
[b]*p*-values are included for the overall *F*-test (diet) and the linear contrast for the increasing level of FFP inclusion.
[c]Effect size: Hedges' *g*. As a guide: |g| ≈ 0.2 denotes small, ≈ 0.5 medium, > 0.8 large effects.

shoulder proportions and loin eye area, as well as indicators of fatness including backfat thickness at the last rib, over the *m. gluteus medius*, leaf fat, and loin eye fat area, also decreased with increasing dietary FFP (linear; $p < 0.05$).

4.4 | Meat Quality

There was no difference in the pH values measured 15 min post-mortem across treatment groups, whereas final pH measured 24 h post-mortem decreased with increasing FFP (linear; $p < 0.001$). Consistent with final pH differences, the effects of FFP diets were observed also on meat colour. Pigs fed FFP diets exhibited a less intense colour, with a lower colour score ($p = 0.10$), higher CIE L value (linear; $p < 0.001$), and higher CIE b value ($p = 0.10$). There was no difference in visually assessed intramuscular fat (marbling).

4.5 | Fatty Acid Profile of the Backfat Tissue

Fatty acids profile of backfat was significantly affected by the level of FFP inclusion (Table 6). The content of palmitic acid (C16:0), the most abundant SFA in pig adipose tissue, and margaric acid (C17:0) decreased linearly with increasing FFP levels (linear; $p \leq 0.020$), while stearic acid (C18:0), the second most abundant SFA, remained unaffected by the dietary treatments. On the other hand, the content of myristic acid (C14:0) and arachidic acid (C20:0) in adipose tissue increased linearly with increasing levels of FFP (linear; $p < 0.001$ for both). These changes in content were small and therefore did not affect total SFA levels. The content of palmitoleic acid (C16:1n-7), oleic acid, vaccenic acid (C18:1n-7) and gondoic acid (C20:1n-9) in the adipose tissue changed with higher levels of FFP. Palmitoleic and vaccenic acid levels decreased, whereas oleic acid, gondoic acid and total MUFA levels increased (linear; $p < 0.001$ for both). The C18:2n-6 content tended to linearly

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TABLE 3 | Feeding behaviour in the grower, finisher I and finisher II period of pigs fed diets supplemented with increasing levels of sugary former food products (FFP).

	Dietary treatments[a]				*p*-value[b]		Effect size[c]		
	FFP-0 (1)	FFP-20 (2)	FFP-40 (3)	SEM	Diet	Linear	1–2	1–3	2–3
Total time spent feeding per day (min)									
Grower period	66.1	57.0	61.9	4.09	0.109	0.317	0.6	0.3	−0.3
Finisher I period	65.3	59.8	64.8	3.85	0.318	0.885	0.4	0.0	−0.4
Finisher II period	57.4	58.0	58.6	2.55	0.882	0.619	−0.1	−0.1	−0.1
Number of daily meals									
Grower period	10.4	10.0	10.3	0.67	0.893	0.901	0.2	0.0	−0.1
Finisher I period	5.6	6.8	6.2	0.40	0.114	0.293	−0.8	−0.4	0.4
Finisher II period	4.6	5.6	5.2	0.36	0.162	0.212	−0.8	−0.5	0.3
Time spent at the feeder per visit (min)									
Grower period	6.4	5.9	6.0	0.49	0.614	0.456	0.3	0.2	−0.1
Finisher I period	12.2	9.2	10.6	0.89	0.030	0.149	0.9	0.5	−0.4
Finisher II period	12.5	10.8	11.7	0.88	0.306	0.440	0.5	0.3	−0.3
Feed intake per visit (g)									
Grower period	193	181	163	13.6	0.303	0.129	0.2	0.6	0.4
Finisher I period	607	501	503	35.1	0.063	0.043	0.8	0.8	0.0
Finisher II period	791	643	679	44.8	0.066	0.087	0.9	0.7	−0.2
Rate of feed intake (g/min)									
Grower period	30	31	28	1.9	0.314	0.327	−0.1	0.3	0.4
Finisher I period	50	56	49	2.7	0.037	0.707	−0.6	0.1	0.7
Finisher II period	63	59	59	2.4	0.223	0.101	0.5	0.5	0.0
Interval between two meals (min)									
Grower period	72.1	71.5	70.6	4.42	0.970	0.808	0.0	0.1	0.1
Finisher I period	111.7	95.0	105.5	4.82	0.060	0.707	1.0	0.4	−0.6
Finisher II period	135.3	114.7	122.5	6.70	0.107	0.187	0.9	0.5	−0.3

[a]FFP-0 = grower, finisher I and finisher II diets with 0% sugary FFP inclusion; FFP-20 = grower, finisher I and finisher II diets with 20% sugary FFP; FFP-40 = grower, finisher I and finisher II diets with 40% sugary FFP.
[b]*p*-values are included for the overall *F*-test (diet) and the linear contrast for the increasing level of FFP inclusion.
[c]Effect size: Hedges' *g*. As a guide: |g| ≈ 0.2 denotes small, ≈ 0.5 medium, > 0.8 large effects.

decrease increasing FFP levels (linear; $p = 0.014$). The levels of the elongation and desaturation products of C18:2n-6, dihomo-gamma-linolenic acid (C20:3n-6), arachidonic acid (C20:4n-6) and adrenic acid (C22:4n-6) also decreased (linear; $p \leq 0.006$). The level of eicosadienoic acid (C20:2n-6) tended to be affected by the diets, with a lower level in the adipose tissue of FFP-20 pigs than in FFP-0 and FFP-40 pigs (Quadratic; $p = 0.039$). The level of C18:3n-3 decreased with higher FFP inclusion levels (linear; $p < 0.001$). Driven by the effect of decreasing n-6 fatty acids, the level of total PUFA decreased linearly with increasing FFP supply (linear; $p < 0.001$). The ratio of Σn-6/Σn-3 increased linearly with increasing FFP in the diet (linear; $p < 0.001$). The desaturation index expressed as the ratios of C16:1n-9/C16:0 linearly decreased with increasing dietary FFP inclusion (linear; $p < 0.001$). By contrast the desaturation index expressed as C18:1n-9/C18:0 was not affected by the dietary treatments. Overall, the inclusion of FFP caused a small but significant shift in the concentration of MUFA and PUFA.

5 | Discussion

This study is a continuation of the previous research at Agroscope investigating the potential impact of FFP on fattening performances of growing and finishing pigs trying to address the knowledge gap regarding the acceptable levels of FFP inclusion. In our study, although pigs were held in one pen, treatments were applied at the individual animal level (e.g., via automatic feeders), so in line with scientific opinion of De Cuyper et al. (2025), we considered individual pig as an experimental unit. The pigs were kept in a spacious pen, allowing ample space to reduce inter-animal interactions. Research shows that increasing floor space allowance leads to less aggression, e.g., skin lesions (Vermeer et al. 2014). Social interactions, particularly competition for resources and hierarchy formation, can mediate behavioural and performance responses, however, when access to resources is not restricted, their influence on individual responses is substantially reduced (Chidgey 2024). In the present case, the feeding system homologised for up to 14 pigs per feeder was used for 12 pigs. Feeder stocking density was thus below the recommended maximum, and, combined with ad libitum feeding, ensured unrestricted access for all pigs. This approach reduced the risk of pseudo-replication bias, however some uncertainty in that respect is to be expected and represents a limitation.

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TABLE 4 | Carcass nutrient and energy content estimated at the start of the experiment and determined by DXA at slaughter, and nutrient and energy deposition rate and deposition efficiency of pigs fed diets supplemented with increasing levels of sugary former food products (FFP).

	Dietary treatments[a]				*p*-value[b]		Effect size[c]		
	FFP-0 (1)	FFP-20 (2)	FFP-40 (3)	SEM	Diet	Linear	1–2	1–3	2–3
At start of the experiment[d]									
Carcass weight, kg	16.44	15.76	16.26	0.331					
Water, kg	11.36	10.89	11.24	0.229					
Ash, kg	0.64	0.61	0.63	0.013					
Fat, kg	1.81	1.73	1.79	0.036					
Protein, kg	2.64	2.53	2.61	0.053					
Gross energy, MJ	132	126	130	2.7					
After slaughter[e]									
Carcass weight, kg	118.43	114.66	110.46	2.145	0.007	0.002	0.5	1.0	0.5
Water, kg	61.64	61.77	60.18	1.073	0.386	0.256	0.0	0.4	0.4
Ash, kg	3.78	3.74	3.55	0.078	0.006	0.006	0.1	0.8	0.7
Fat, kg	35.60	32.83	31.67	1.060	0.004	0.001	0.7	1.0	0.3
Protein, kg	18.86	18.90	18.39	0.342	0.378	0.248	0.0	0.4	0.4
Gross energy, MJ	1788	1682	1626	44.0	0.006	0.002	0.7	1.0	0.4
Expressed as % of carcass weight									
Water	51.41	52.73	52.90	0.456	0.009	0.005	−0.8	−0.9	−0.1
Ash	3.16	3.20	3.21	0.052	0.196	0.314	−0.2	−0.3	−0.1
Fat	29.70	27.94	27.82	0.629	0.014	0.009	0.8	0.8	0.1
Protein	15.73	16.14	16.16	0.142	0.014	0.009	−0.8	−0.8	0.0
Gross energy, MJ/kg	14.92	14.33	14.29	0.212	0.013	0.008	0.8	0.8	0.1
Deposition rate in carcass									
Ash, g/d	24	24	23	0.60	0.026	0.021	0.0	0.5	0.5
Fat, g/d	258	240	231	7.1	0.007	0.002	0.7	1.1	0.4
Protein, g/d	124	126	122	2.4	0.327	0.466	−0.2	0.2	0.5
Gross energy, MJ/d	12.7	12.0	11.6	0.28	0.009	0.002	0.7	1.1	0.4
Deposition efficiency in carcass									
Protein, %	31.37	33.44	34.08	0.784	0.005	0.002	−0.7	−1.0	−0.2
Gross energy, %, based on ingested amount of									
Gross energy	26.91	25.96	25.64	0.282	0.009	0.003	0.9	1.3	0.3
Digestible energy	33.34	32.93	33.58	0.366	0.454	0.649	0.3	−0.2	−0.5
Net energy	46.35	46.58	47.98	0.527	0.075	0.036	−0.1	−0.9	−0.7

[a]FFP-0 = grower, finisher I and finisher II diets with 0% sugary FFP inclusion; FFP-20 = grower, finisher I and finisher II diets with 20% sugary FFP; FFP-40 = grower, finisher I and finisher II diets with 40% sugary FFP.
[b]*p*-values are included for the overall *F*-test (diet) and the linear contrast for the increasing level of FFP inclusion.
[c]Effect size: Hedges' *g*. As a guide: |g| ≈ 0.2 denotes small, ≈ 0.5 medium, > 0.8 large effects.
[d]Estimated using average nutrient and energy contents per kg BW (Ruiz-Ascacibar et al. 2017): Carcass weight = 0.7143 × BW; Water = 0.4927 × BW; Ash = 0.0276 × BW; Fat = 0.0784 × BW; Protein = 0.1144 × BW; Gross energy = 0.0057 × BW. BW at slaughter was not different ($p = 0.334$) between dietary treatments, therefore it is assumed that nutrient and gross energy content of the carcass was also similar.
[e]Calculated according to Kasper et al. (2021), based on measured DXA values.

Previous study (Tretola et al. 2024) has shown that 30% inclusion of sugary FFP did not adversely affect the growth of fattening pigs up to a standard slaughter weight. The present study extends the existing knowledge by testing further addition of sugary FFP (namely 20% and 40% inclusion) while also prolonging the fattening period, as used in heavy pig production. Additionally, this production system requires specific meat quality referred to as seasoning aptitude for long-term dry-curing process (Russo and Nanni Costa 1995). In this context technological quality (meat pH, meat water holding capacity and fat tissue saturation level) is of particular importance.

5.1 | Effects on Fattening Performance

Pigs can adjust voluntary FI in response to dietary characteristics. It is generally assumed that pigs adapt their FI in an effort to maintain a constant daily energy intake. However, FI regulation is a complex process, with environmental, social, and dietary factors, along with individual response of animals, all playing a role in shaping voluntary FI (Li and Patience 2017). Although the experimental diets in our study were balanced for energy, amino acids, protein, and fibre, increasing FFP levels

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TABLE 5 | Carcass characteristics and meat quality traits energy of pigs fed diets supplemented with increasing levels of sugary former food products (FFP).

	Dietary treatments[a]				*p*-value[b]		Effect size[c]		
	FFP-0 (1)	FFP-20 (2)	FFP-40 (3)	SEM	Diet	Linear	1–2	1–3	2–3
Hot carcass weight, kg	121.4	117.9	113.6	2.13	0.009	0.002	0.4	1.0	0.6
Cold carcass weight, kg	118.2	114.8	110.6	2.12	**0.011**	0.003	1.1	2.2	1.0
Carcass yield, %[b]	82.28	81.15	80.10	0.281	0.004	0.001	0.9	0.9	0.0
Cooling purge, %	2.7	2.6	2.6	0.03	0.633	0.358	1.0	1.5	0.4
Leaf fat, %	3.2	2.5	2.2	0.19	< 0.001	< 0.001	0.8	0.4	−0.3
Loin, %	23.6	22.9	23.2	0.25	0.145	0.202	0.8	1.2	0.4
Ham, %	24.4	21.3	19.6	1.11	0.003	< 0.001	−0.7	−0.7	0.0
Shoulder, %	12.8	13.2	13.2	0.16	0.022	0.014	−0.2	0.3	0.5
Belly portion, %	19.7	19.8	19.5	0.18	0.451	0.452	0.4	1.0	0.6
Muscularity proxies									
Loin eye area, cm^2	48.2	47.2	46.1	0.97	0.185	0.069	0.3	0.6	0.3
Muscle depth, mm	75	74	72	1.5	0.408	0.195	0.2	0.6	0.4
Fatness proxies									
Loin eye backfat area, cm^2	24.1	24.7	24.7	0.20	0.047	0.026	−0.8	−0.8	0.0
Backfat at withers, mm	41	39	39	1.5	0.277	0.155	0.4	0.4	0.0
Backfat at last rib, mm	30	28	27	1.0	0.074	0.030	0.6	0.8	0.3
Backfat over *m. gluteus medius*	26	23	23	1.2	0.024	0.015	0.7	0.7	0.0
Meat quality									
pH 15 min	6.68	6.76	6.70	0.054	0.374	0.773	−0.4	−0.1	0.3
pH, 24 h	5.45	5.39	5.36	0.018	0.003	< 0.001	0.9	1.4	0.5
Drip loss, %	4.3	3.8	4.6	0.52	0.463	0.663	0.3	−0.2	−0.4
Colour score (1–6)	3.5	3.3	3.2	0.14	0.233	0.100	0.4	0.6	0.2
Colour parameters CIE L*	52.6	54.5	54.9	0.50	0.001	< 0.001	−1.1	−1.3	−0.2
CIE a*	8.9	8.5	8.7	0.28	0.453	0.501	0.4	0.2	−0.2
CIE b*	7.0	7.5	7.5	0.20	0.101	0.074	−0.7	−0.7	0.0
Marbling (1–7)	3.0	2.7	2.6	0.21	0.377	0.218	0.4	0.5	0.1

[a]FFP-0 = grower, finisher I and finisher II diets with 0% sugary FFP inclusion; FFP-20 = grower, finisher I and finisher II diets with 20% sugary FFP; FFP-40 = grower, finisher I and finisher II diets with 40% sugary FFP.
[b]*p*-values are included for the overall *F*-test (diet) and the linear contrast for the increasing level of FFP inclusion.
[c]Effect size: Hedges' *g*. As a guide: |g| ≈ 0.2 denotes small, ≈ 0.5 medium, > 0.8 large effects.

raised simple sugars and fat while reducing starch, thus producing a complex effect on FI. Our findings differ from the results of Mazzoleni et al. (2023), who reported no effect of a 30% FFP inclusion in the growing period. In the present study, pigs receiving 40% FFP showed a marked reduction in FI, suggesting that this inclusion level may have been too high in young pigs. In fact, the relative increase in dietary content of water soluble carbohydrates due to FFP inclusion was the greatest in grower phase (2.5- and 3.8-fold for 20% and 40% FFP inclusion, respectively, Supporting Information S1: Figure S1). It has been reported that weaning piglets submitted to a long-term exposure to concentrated sucrose and maltodextrin solutions reduced their FI and growth (Guzmán-Pino et al. 2015). Moreover, a complementary study of the mentioned experiment reported a limited modulation of liver proteome and plasma (Manoni et al. 2024). Increasing the content of simple carbohydrates in a pig's diet has been suggested to enhance growth rates. For example, Camp et al. (2003) found that adding sucrose at levels up to 15% led to increased daily weight gain, yet, surprisingly, had no effect on overall FI. However, a diet containing 50% sucrose fed to pigs over the course of a year was found to reduce overall growth rate (Bruckdorfer and Yudkin 1975), highlighting potential negative long-term effects of excessive sucrose inclusion. As shown in mice, high sugar and fat combination, as was the case in the diets with FFP the present study) can lead to adverse metabolic outcomes such as reduced glucose tolerance and insulin sensitivity, depending on the dietary context (Wali et al. 2023). A high-fat and high-caloric diet was also shown to induce metabolic disorders in guinea pigs; and this occurred without an increase in BW or fat accumulation (Muller et al. 2021). In fact, some studies even reported a lower tissue fat percentage compared to control groups (Tveden-Nyborg et al. 2016). The highest inclusion level of FFP applied in the present study may represent a limit, as the effect on FI was highly significant ($p < 0.001$, large effect size 1.3–2.4) in the grower period, and not entirely negligible in the finisher period ($p \leq 0.11$, a medium effect size, i.e., 0.4–0.5). Because blood metabolites and indicators of digestive

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TABLE 6 | Fatty acid profile of the adipose tissue of pigs fed grower and finisher diets supplemented with increasing levels of sugary former food products (FFP).

	Dietary treatments[a]				*p*-value[b]		Effect size[c]		
	FFP-0 (1)	FFP-20 (2)	FFP-40 (3)	SEM	Diet	Linear	1–2	1–3	2–3
C14:0	1.45	1.72	2.02	0.037	< 0.001	< 0.001	−2.0	−4.3	−2.3
C16:0	25.24	24.20	23.70	0.275	< 0.001	0.001	1.1	1.6	0.5
C17:0	0.28	0.27	0.25	0.010	0.045	0.020	0.3	0.8	0.6
C18:0	13.80	13.70	13.52	0.300	0.759	0.458	0.1	0.3	0.2
C20:0	0.20	0.21	0.23	0.006	< 0.001	< 0.001	−0.5	−1.4	−0.9
SFA	41.34	40.58	40.34	0.516	0.219	0.097	0.4	0.5	0.1
C16:1n-7	2.27	1.91	1.73	0.078	< 0.001	< 0.001	1.3	1.9	0.6
C18:1n-9	42.01	43.76	44.53	0.383	< 0.001	< 0.001	−1.3	−1.8	−0.6
C18:1n-7	3.01	2.60	2.34	0.054	< 0.001	< 0.001	2.1	3.5	1.3
C20:1n-9	0.90	0.99	1.22	0.048	< 0.001	< 0.001	−0.5	−1.9	−1.3
MUFA	49.29	50.34	50.88	0.457	0.017	0.005	−0.6	−1.0	−0.3
C18:2n-6	7.60	7.43	7.14	0.154	0.045	0.014	0.3	0.8	0.5
C20:2n-6	0.35	0.34	0.36	0.012	0.067	0.273	0.2	−0.2	−0.5
C20:3n-6	0.06	0.05	0.05	0.002	0.019	0.006	1.4	1.4	0.0
C20:4n-6	0.15	0.14	0.12	0.005	< 0.001	< 0.001	0.6	1.7	1.1
C22:4n-6	0.05	0.04	0.04	0.004	< 0.001	< 0.001	0.7	0.7	0.0
C18:3n-3	0.58	0.55	0.49	0.013	< 0.001	< 0.001	0.6	1.9	1.3
PUFA	9.31	9.02	8.71	0.180	0.029	< 0.001	0.4	0.9	0.5
Σn-6/Σn-3 ratio	13.09	13.67	14.71	0.133	< 0.001	< 0.001	−1.2	−3.4	−2.2
C16:1n-7/C16:0	0.09	0.08	0.07	0.003	< 0.001	< 0.001	0.9	1.9	0.9
C18:1n-9/18:0	3.09	3.20	3.31	0.092	0.150	0.054	−0.3	−0.7	−0.3

Note: Fatty acids with a concentration below 0.1% were not reported. However, they were included in the calculation of the sum of saturated fatty acids (SFA), monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA).
[a]FFP-0 = grower, finisher I and finisher II diets with 0% sugary FFP inclusion; FFP-20 = grower, finisher I and finisher II diets with 20% sugary FFP; FFP-40 = grower, finisher I and finisher II diets with 40% sugary FFP.
[b]*p*-values are included for the overall *F*-test (diet) and the linear contrast for the increasing level of FFP inclusion.
[c]Effect size: Hedges' *g*. As a guide: |g| ≈ 0.2 denotes small, ≈ 0.5 medium, > 0.8 large effects.

disturbances were not monitored in the present experiment, linking the observed changes in feeding behaviour to specific underlying physiological mechanisms is limited. In particular, the potential gut-mediated feedback mechanisms, such as changes in digestion, fermentation patterns, or postprandial metabolic responses, cannot be evaluated from the current dataset. However, to address this, intestinal contents were collected for downstream analyses of digestive-related mechanisms, including microbiome profiling. These analyses are ongoing and will be reported in a subsequent publication, thereby complementing the feeder-derived behavioural results presented here. Considering the economic implications, the overall reduction in feed conversion ratio with increasing inclusion levels is a favourable outcome, further supported by the positive impact on feed–food competition; however, at present, current cost of this feed remains a major limitation for its use in practice.

5.2 | Effects on Feeding Behaviour

In the grower phase, feeding behaviour was mostly unaffected, while in the finisher phase, trends aligned with the expected effects of sugar- and fat-rich diets on satiety. It has been hypothesised that adding artificial sweeteners into pig diets affects their feeding behaviour by increasing the frequency of visits to the feeder (Sterk et al. 2008). Pigs fed diets rich in rapidly digestible starch have also been shown to have shorter inter-meal intervals and meal durations (Souza da Silva et al. 2014). Since the starch present in FFPs is highly digestible (De Vries et al. 2012) and has a high glycaemic index potential (Ottoboni et al. 2019), this can be linked to a reduction in satiety duration (Bolhuis et al. 2008). A more detailed temporal analysis of feeding behaviour (e.g., meal size distribution and diurnal patterns) could therefore provide additional insight into the mechanisms underlying these effects. However, as these indicators are not currently derived by our processing algorithm, we restricted the present analysis to daily-level feeding behaviour summaries, consistent with the main objectives of the study.

5.3 | Effects on Body Composition and Carcass Traits

While in a study of Mazzoleni et al. (2023) a 30% inclusion of sugary FFP had no effect on the body composition of pigs, our study, on the contrary, showed that body composition was affected by FFP inclusion. Despite higher dietary fat levels, carcass fat content decreased with increasing FFP inclusion. Since

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the diets were isoenergetic and isoproteic, this outcome is likely due to reduced FI, and consequently lower energy intake, which influences fat deposition (Nürnberg et al. 1998). In this study, the efficiency of protein and net energy deposition increased with higher FFP inclusion, unlike the findings of Mazzoleni et al. (2023), who observed no effect with a 30% inclusion of sugary FFP. A possible explanation for this discrepancy is that Mazzoleni et al. (2023) calculated efficiency based on the empty body, whereas in our study, it was assessed on the carcass. Additionally, the longer fattening period in our study may have further contributed to the observed differences. The results on carcass traits corroborate with the DXA determined body composition, confirming the linear decrease of carcass yield and fatness indicators with increasing inclusion of FFP in the diet of pigs. Decreased carcass fatness observed with increased FFP inclusion was not expected, however it is supported by the observed lower activity of lipogenic enzymes in fat tissue (Poklukar et al. 2026) and is consistent with reports from biomedical research. Namely, high-fat and high-caloric dietary regime inducing dyslipidemia in guinea pigs was not associated with increase in BW or fat mass (Muller et al. 2021) or showed a decreased tissue fat percentage compared with controls (Tveden-Nyborg et al. 2016). Diets high in sugar have been associated with reduced glucose tolerance and insulin sensitivity, however these effects vary by tissue, energy balance, and duration of exposure (Macdonald 2016).

5.4 | Effects on Meat Quality

Lower ultimate pH observed for pigs on FFP diet indicate higher glycogen reserves in the moment of slaughter. Namely, muscle glycogen concentration at the time of slaughter determines the extent of muscle pH decline, which in turn affects various meat quality traits (Bendall and Swatland 1988), such as pH, colour, and water-holding capacity which also explains higher CIE L* and b* parameters. Different dietary energy sources have been shown to impact muscle glycogen storage at slaughter (Rosenvold et al. 2001; Bee et al. 2006) and sugary diets may alter glucose metabolism and increase glycogen deposition resulting in lower post-mortem pH (Fernandez and Tornberg 1991). However, as noted in the review by England et al. (2013), high inclusion rates may be needed, as grower and finisher pig diets with up to 15% sucrose showed no effects on glycogen content or postmortem metabolism (Camp et al. 2003). The potential implications of the observed reduction in ultimate pH for dry-cured meat processing would be primarily through its effects on the dynamics of salt diffusion and uptake.

5.5 | Effects on Fatty Acid Profile of Fat Tissue

It is well established that fatty acid profile in monogastric animals, such as pigs, is largely influenced by their diet (Wood et al. 2008). It is assumed that when animals consume a diet high in sugars (especially simple sugars like sucrose), excess glucose and fructose can be converted into fatty acids through a process known as de novo lipogenesis (Geidl-Flueck and Gerber 2023) which typically leads to an increased proportion of SFA or MUFA in fat tissue (Wood et al. 2008). The effect of sugary FFP was evidenced as a shift to higher MUFA (large effect size) but slightly lower SFA (medium effect size). In contrast, the lower PUFA levels in fat tissue align with both the reduced total FI and the decreasing dietary PUFA content associated with increasing FFP inclusion. The increased Σn6:Σn3 PUFA ratio with FFP inclusion seems to be due to the decrease of C18:2n-6. The dietary context of this study is relatively complex, as the increasing inclusion of sugary FFP leads to higher sugar levels, which, a priori, would be expected to enhance de novo synthesis of SFA and MUFA. As reported in mice, de novo fat synthesis can be reduced in parallel with increased dietary fat intake (Duarte et al. 2014). Moreover, the observed reduction in body adiposity is consistent with established associations between adipose tissue fatty acid composition and fatness, notably the inverse relationship between PUFA levels and adiposity (Wood et al. 2008). Our results suggest an adaptive body response to the diet. Potential mechanisms can be related to reduced de novo lipogenesis and adaptive desaturation of SFA to MUFA (Flowers and Ntambi 2008).

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Ethics Statement

The protocol for this experiment was set in accordance with Swiss guidelines for animal welfare and received authorisation (2021-35-FR) from the Swiss Federal Committee for Animal Care and Use (Canton Fribourg-Switzerland). The trial was conducted at the Agroscope Experimental Swine Research Centre in Posieux (Fribourg, Switzerland).

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request. None of the data were deposited in an official repository.

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