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Sugary and salty former food products in pig diets affect energy and nutrient digestibility, feeding behaviour but not the growth performance and carcass composition

S. Mazzoleni[a], M. Tretola[a,b], A. Luciano[a], P. Lin[a], L. Pinotti[a,c], G. Bee[b,*]

[a] Department of Veterinary Medicine and Animal Science, DIVAS, University of Milan, 26900 Lodi, Italy
[b] Agroscope, Institute for Livestock Sciences, 1725 Posieux, Switzerland
[c] CRC I-WE, Coordinating Research Centre: Innovation for Well-Being and Environment, University of Milan, 20134 Milan, Italy

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ABSTRACT

Former foodstuff products (**FFPs**) are promising alternative ingredients for reducing the waste of natural resources and the environmental impact of food production. This study investigates the effects of salty and sugary FFPs on growth performance, apparent total tract digestibility (**ATTD**), and growing-finishing pigs' empty body and carcass composition. Thirty-six Swiss Large White male castrated pigs were assigned to three growing (G) and finishing (F) diets: (1) standard diet (**ST**), 0% FFPs; (2) 30% conventional ingredients replaced by sugary FFPs (**SU**); and (3) 30% conventional ingredients replaced by salty FFPs (**SA**). Faecal samples from 24 selected pigs were collected to assess the ATTD of gross energy, crude fibres, and CP. The BW was measured weekly, while feed intake was determined daily. Average daily gain (**ADG**), average daily feed intake (**ADFI**), feed conversion ratio (**FCR**), and ATTD were calculated for both the growing and finishing periods. Pigs' body composition was determined at ≥20 and ≥98 kg using dual-energy X-ray absorptiometry. In the growing but not finishing period, the FCR was lower ($P < 0.05$) in ST compared to SA and SU pigs. Considering the entire growing and finishing period, neither the inclusion level nor the type of FFPs influenced ($P > 0.05$) ADG, ADFI, FCR, or BW at slaughter. In both the growing and finishing periods, the gross energy ATTD was higher ($P < 0.05$) in the SA than in the ST group, with intermediate values in the SU group. In the growing period, the CP ATTD was higher ($P < 0.05$) in the SA than in the SU and ST groups. In the finishing period, the crude fibre ATTD was lower ($P < 0.05$) in the SA and SU than in the ST group. Throughout the overall period, the average daily fat intake was higher ($P < 0.05$) in pigs fed an SU diet, even though both categories of FFPs had no ($P > 0.05$) effects on the parameters related to the pigs' body composition (e.g., average daily fat weight gain). Finally, the carcasses of the SU group had the thickest belly fat, even though the total fat content was similar among the groups. This study confirms that including FFPs has no detrimental effects on growth performance or live body/carcass composition in growing and finishing pigs.

Implications

Reintroducing former food products in the animal feed chain is a promising solution to reduce the waste of natural resources and the environmental impact of food production. Recent studies investigated the effects of a partial replacement of grains by sugary or salty former food products in young pigs. Still, there is a lack of knowledge concerning their impact on growing-finishing pigs. The present study suggests that partial substitution of standard ingredients with sugary and salty former food products in the diets of growing-finishing pigs is possible without any adverse effects on growth performance and animals' feeding behaviour.

Introduction

The livestock farming system faces a wide range of complex challenges. As the global population grows to over 9 billion by 2050 (Bernal et al., 2021), the demand for food will undoubtedly increase. Considering that around 30–70% of the yielded grains in the world are intended for livestock (Elferink et al., 2008), one of the main issues is the competition between feed and food since the production of both requires large arable land areas and high resources input, which are limited. However, the current paradox

* Corresponding author.
E-mail address: giuseppe.bee@agroscope.admin.ch (G. Bee).

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is that about one-third of the food intended for human consumption is wasted globally (Pinotti et al., 2020). At the European level, approximately 88 million tonnes of food waste are generated annually (Corrado and Sala, 2018). Pinotti et al. (2021) reported that several terms refer to different food effluents, such as food losses, food waste, and former foodstuff products (**FFPs**). While food losses can arise in the early stages of the food production chain, in which a decrease in food quantity or quality can occur (e.g., lack of infrastructural capacities of postharvest activities), food waste refers to the later stages of the food supply chain because it includes food biomasses collected from restaurants or derived from retail and household food waste (Pinotti et al., 2021). FFPs and food leftovers are food effluents that are different from household waste or restaurant/catering waste. Specifically, FFPs are animal feed ingredients composed of processed and ready-to-eat food products that are no longer suitable for human consumption due to logistical, manufacturing, or packaging defects. Thus, while food waste cannot reenter the food chain (Pinotti et al., 2021), FFPs are reported in the catalogue of feed materials, as they are suitable for feeding animals and do not represent a form of waste treatment but improve the circular economy in food production (European Commission, 2018). Nutrient losses and the production of feed and food are important contributors to environmental pollution and the depletion and degradation of natural resources (Corrado and Sala, 2018). Consequently, this could threaten food security. In this regard, it is important to find ways to valorise these food losses so that they can partially replace conventional crops used as feed to mitigate feed–food competition and limit the losses of natural resources.

FFPs are valuable sources of nutrients owing to the presence of easily digestible cooked starch, simple sugars, fat, and energy compared to grain. These characteristics make them suitable for the nutrition of young animals (Ottoboni et al., 2019; Luciano et al., 2020). These materials, based on the starting ingredients, can be classified into two categories: (i) salty leftovers, mainly obtained through bakery products, which include pasta, bread, and salty snacks, and (ii) sugary leftovers, obtained through confectionery products, such as chocolate, breakfast cereals, and cookies. The results of recent studies carried out on postweaning piglets have shown that a partial replacement of traditional energy sources with FFPs (without distinguishing between sugary and salty products) does not have detrimental effects on growth performance, diet digestibility (Tretola et al., 2019a), and metabolic profile. However, the greater quantity of simple sugars in sugary compared to salty FFPs may impact animals' performance differently. Firstly, simple sugars can alter the osmotic balance of the enteric epithelium and draw water into the intestinal lumen, resulting in nutritional diarrhoea. Secondly, processed starch can increase the diet's digestibility. In addition to simple sugars and starch, bakery products contain a considerable amount of saturated fatty acids (FAs) from ingredients such as butter, margarine, and partially hydrogenated vegetable oils (Demirkesen and Mert, 2020; Pinotti et al., 2021; Gutiérrez-Luna et al., 2022). It is crucial to assess the potential effects of these fats on animals' growth performance, nutrient and energy deposition in the empty body during the growing–finishing period and at slaughter on the carcass composition. The digestibility of individual FAs increases with increasing unsaturation and decreases with FA chain length (Duran-Montgé et al., 2007), suggesting that saturated FAs are less digestible. This would reduce the available energy and could overestimate the digestible energy content of sugary FFPs compared to salty FFPs. Therefore, it is crucial to evaluate these two categories of FFPs separately. Compared to unprocessed cereals, FFPs are characterised by a higher glycaemic index potential, which seems to be associated with a higher starch/sugar hydrolysis index (Ottoboni et al., 2019). The latter could lead to the hypothesis that pigs fed diets supplemented with FFPs may rapidly return to a state of hunger, which could then lead to increased feed intake (Luciano et al., 2021). Additionally, a higher starch digestion rate could lead to a rapid increase in the plasma levels of metabolites (e.g., glucose) and nutrients (Tretola et al., 2019a). Taken together, utilising FFPs in growing-fattening pigs' diets may have a positive influence on the growth performance of animals. Apart from the evaluation of growth performance, it is important to know the exact pig's body chemical composition and nutrient deposition. The FFPs supplemented diets could have led to changes in feeding behaviour and nutrient deposition rate. Due to the high content of highly digestible carbohydrates especially fat deposition rate might be increased. In fact, it is known that both the nature of carbohydrates and its digestion speed are relevant in the regulation of the metabolism of adipose tissue (Martin et al., 2018). To assess the value of the FFPs, determining the changes in body nutrient composition and deposition rate is of great value.

To our knowledge, no studies have investigated the effects of sugary or salty FFPs at high dietary inclusion levels during the growing-finishing period. Based on the results of previous studies (Tretola et al., 2019a; Luciano et al., 2021), the hypothesis of the present study was that the inclusion of 30% salty or sugary FFPs in a well-balanced diet offered during the whole growing-finishing period had no detrimental effects on growth performance and nutrient and energy digestibility. However, due to differences in the appetence of the diets and their high sugar and also salt contents, the pig feeding behaviour could be altered compared to the conventional diets. Moreover, the remarkable amount of SFAs could lead to changes in body composition, especially with regard to fat distribution. In order to verify these hypotheses, the objective of this study was to evaluate the effects of partial replacement of cereals with sugary or salty FFPs in pig diets on growth performance, diet digestibility, whole empty body composition, and nutrient deposition efficiency.

Material and methods

Animals, diets, and slaughtering procedure

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).

Thirty-six Swiss Large White castrated-male piglets originating from five litters were used in this study. At the start of the growing period (22.38 ± 1.70 kg BW; [mean ± SD]), pigs were assigned within litters to three experimental diets: standard (**ST**), salty (**SA**), and sugary (**SU**). The piglets in the three groups were equal in terms of initial BW. To formulate the SA and SU diets, salty FFPs containing products such as pasta, bread, and salty snacks and sugary FFPs containing products such as chocolate, breakfast cereals, and cookies were used, respectively. The FFPs were classified into salty and sugary based on the total sugar content expressed in sucrose. The chemical composition of the pure SA and SU FFPs used to formulate the experimental diets was equal to the two pure FFPs used for the diets in postweaned piglets by Luciano et al. (2021) (Supplementary Table S1). The growing and finishing diets were formulated based on the Swiss feeding recommendations for pigs (Agroscope, 2022, Table 1). To formulate the ST growing diet and the ST finishing diet, a reference BW of 40 kg and 80 kg was used, respectively. For the SA and SU growing and finishing diets, a portion of the cereals and fats included in the ST growing and ST finishing diets were replaced by 30% salty and sugary FFPs. Regardless of the treatment, the growing and finishing

Table 1
Diet composition and nutrient and digestible energy content (g/kg or MJ/kg on DM) of the unsupplemented standard growing (ST-G) and finishing (ST-F) diets and the growing and finishing diets supplemented with 30% of salty (SA-G and SA-F) or sugary (SU-G and SU-F) former food products fed to growing-finishing pigs.

	Dietary treatments[1]					
	Growing diets			Finishing diets		
Ingredient, %	ST-G	SA-G	SU-G	ST-F	SA-F	SU-F
Barley	41.10	39.70	38.00	46.40	41.30	41.80
Wheat	30.00	–	–	30.00	–	–
Salty FFPs[2]	–	30.00	–	–	30.00	–
Sugary FFPs[3]	–	–	30.00	–	–	30.00
Fat	2.69	–	0.79	2.22	–	0.68
Potato protein	5.00	5.00	5.00	5.00	5.00	5.00
Soybean meal	6.59	6.16	7.36	3.55	2.77	4.03
Wheat bran	4.34	9.06	8.76	3.93	12.30	9.87
Dried beet pulp	5.15	5.15	5.15	4.50	4.50	4.50
L-Lysine-HCl	0.26	0.26	0.23	0.10	0.12	0.09
DL-Methionine	0.02	0.01	0.02	–	–	–
L-Threonine	0.02	0.03	0.02	–	–	–
L-Tryptophan	–	–	0.002	–	–	–
MCP	0.45	0.45	0.47	0.13	0.11	0.16
Lime, carbonic acid	1.53	1.51	1.48	1.20	1.17	1.19
Sodium chloride	0.16	–	–	0.27	–	–
Pellan[4]	0.30	0.30	0.30	0.30	0.30	0.30
Celite 545	2.00	2.00	2.00	2.00	2.00	2.00
ALP-S 467 Mast[5]	0.40	0.40	0.40	0.40	0.40	0.40
Natuphos 5000 G	0.01	0.01	0.01	0.01	0.01	0.01
Analysed nutrient composition (g/kg DM)						
Total ash	68.00	74.00	72.00	62.00	65.00	64.00
Crude fat	52.00	53.00	61.00	45.00	53.00	59.00
CP	173.00	174.00	176.00	152.00	151.00	153.00
Crude fibre	42.00	40.00	39.00	42.00	39.00	40.00
Sodium	1.30	3.70	1.50	1.70	3.20	1.70
SFA	18.00	12.00	18.00	16.00	12.00	20.00
MUFA	19.00	26.00	20.00	14.00	29.00	25.00
PUFA	17.00	16.00	14.00	16.00	18.00	18.00
Calculated						
Digestible phosphorus (g/kg DM)	2.90	2.90	2.90	2.20	2.20	2.20
Digestible lysine (g/kg DM)	8.30	8.30	8.30	6.20	6.20	6.20
DE (MJ/kg DM)	13.70	13.70	13.70	13.70	13.70	13.70

Abbreviations: MCP = monocalcium phosphate; SFAs = saturated fatty acids; MUFA = monounsaturated fatty acid; PUFA = polyunsaturated fatty acid; DE = digestible energy.
[1] All growing and finishing diets were formulated based on the energy and nutrient requirements of pigs with a BW of 40 and 80 kg (Agroscope, 2022).
[2] Salty former foodstuff products.
[3] Sugary former foodstuff products.
[4] Binder that aids in pellet formation.
[5] Mineral-vitamin premix that 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 MnO_2.

diets were isoenergetic and isonitrogenous. All diets included microbial phytase at 500 FTU/kg (0.16 digestible P/100 FTU) and prepared as pellets (<70 °C). The digestible and net energy coefficients from each feed ingredient were obtained from the Swiss (Agroscope, 2022) and French (Noblet et al., 2003) feed databases, respectively. Considering the relative amount of each feed ingredient in the diets, digestible and net energy content were calculated.

Pigs were reared in a single-group pen equipped with three single-space computerised feeders (Mastleistungsprüfung MLP-RAP; Schauer Agrotronic AG, Sursee, Switzerland), which allowed for recording individual feed intake. The pigs had *ad libitum* access to fresh water and to the growing and finishing diets from 20 to 60 kg BW and from 60 kg BW to slaughter, respectively. Pigs were switched to the finishing diet when at the weekly weighing, their BW was ≥60 kg. The BW of all animals was monitored weekly on Monday. The total feed intake, average daily gain (**ADG**), average daily feed intake (**ADFI**), and feed conversion ratio (**FCR**) were calculated separately for the growing and finishing phases as well as for the overall growth period.

On the day after the pigs reached ≥100 kg BW at the weekly weighing, 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. Furthermore, 30 min after exsanguination, the weights of hot carcasses were assessed, and subsequently, the carcasses were chilled at 2 °C for 24 h.

Feeding behaviour

The previously described automatic feeders recorded all daily visits to the feeder, feed intake per visit, and time spent at the feeder. The temporal basis for describing the feeding behaviour of the animals is represented by the day rather than the single meal (Carcò et al., 2018). As proposed by De Haer and Merks (1992), within-meal feeder visits shorter than 5 min were grouped and considered a single meal. The data about the total feed intake, total feeder visits, and total feeding time per day per pig were used to calculate the average total time spent feeding per day (expressed in minutes), the average frequency of feeder visits, the average time per visit (expressed in minutes), the mean feed intake per visit (expressed in grams), the mean rate of feed intake (expressed in g/min), and the interval between two meals (expressed in minutes).

Digestibility trial

The digestibility trial was conducted with 24 pigs (eight pigs from each treatment) in the middle of both the growing (≥40 kg BW) and the finishing period (≥80 kg BW). Faeces samples were collected from each pig in the morning from 08:00 on four consecutive days and subsequently pooled per pig. The animals were moved to individual cleaned pens for 2 h, and then, a fresh faecal sample of 150 g was collected and stored at −20 °C until further processing. An indigestible marker (celite) was added to all growing and finishing diets. The apparent total tract digestibility (**ATTD**) of gross energy, crude fibre, and CP were determined using the index method described by Jang et al. (2014).

Dual-energy X-ray absorptiometry measurements

To obtain the water, ash, protein, fat, and energy contents of the empty bodies and carcasses, a GE Lunar dual-energy X-ray absorptiometry (**DXA**) (Lunar i-DXA, GE Healthcare Switzerland, Glattbrugg, Switzerland) with a narrow-angle fan beam (Collimator Model 42129) was used, as previously described by Kasper et al. (2021).

All animals were scanned at the start of the trial (≥20 kg BW) (Fig. 1) and when they reached ≥98 kg BW, which was one week before the slaughter (Fig. 2). To avoid any movement during scanning, pigs were anaesthetised with isoflurane (Attane, Piramal Critical Care, Inc., Bethlehem, PA, USA), as previously described (Kasper et al., 2021). After the DXA scans, the pigs were brought back to the pen. One day postmortem, the left-side cold carcass was weighed and then scanned using the DXA. Subsequently, the left carcass side was dissected, and the primal cuts and fat cover were weighed as described by Bee (2002). The carcass yield, expressed as the proportion of the hot carcass weight over the BW at slaughter, and carcass length were also assessed.

Laboratory analyses

On feed samples, DM was determined gravimetrically after drying at 105 °C for 3 hours. Ash content was determined after 3 hours at 550 °C. The CP content (total N × 6.25) was analysed with a LECO FP-2000 analyzer (Leco, Mönchengladbach, Germany) (International Organisation for Standardisation (ISO, 2008)). In the diets, crude fibre and ether extract were determined according to methods 6.1.4 and 5.1.1 of Naumann and Basler (1997). Feed samples were hydrolysed in 10% (v/v) HCl for 1 hour to determine the dietary crude fat content. The hydrolysate was dried and extracted with petroleum ether using the Büchi SpeedExtractor E 916 (Büchi Labortechnik AG, Flawil, Switzerland). The fatty acid profiles of the feed were determined in lyophilised samples as described by Kragten et al. (2014). Briefly, lipids were trans methylated for 3 h at 70 °C using 5% methanolic HCl as an acid reagent. The methyl esters were neutralised with a potassium carbonate solution and purified on silica gel. Fatty acid methyl esters were analysed by gas chromatography (6850 series; Agilent Technologies AG, Basle, Switzerland) equipped with a flame ionisation detector (detector temperature 250 °C). Nonadecanoic acid methyl ester (19:0) was used as internal standard.

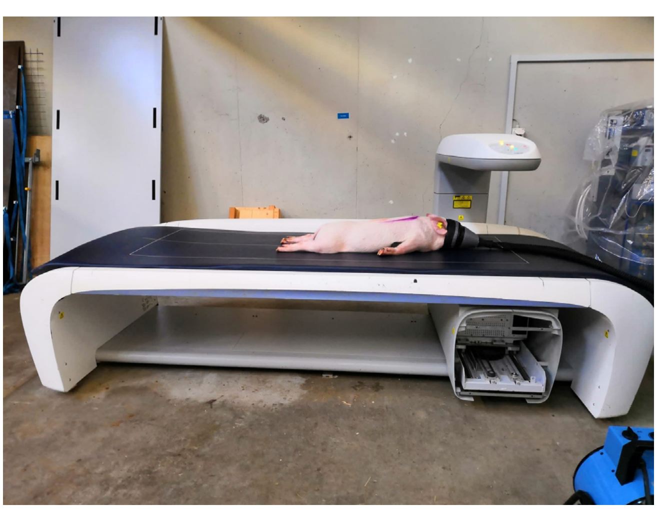

Fig. 1. Position of a ≥20 kg live growing pig on the dual-energy X-ray absorptiometry (DXA) apparatus during scanning under anaesthesia to obtain the empty body's water, ash, protein, fat, and energy contents.

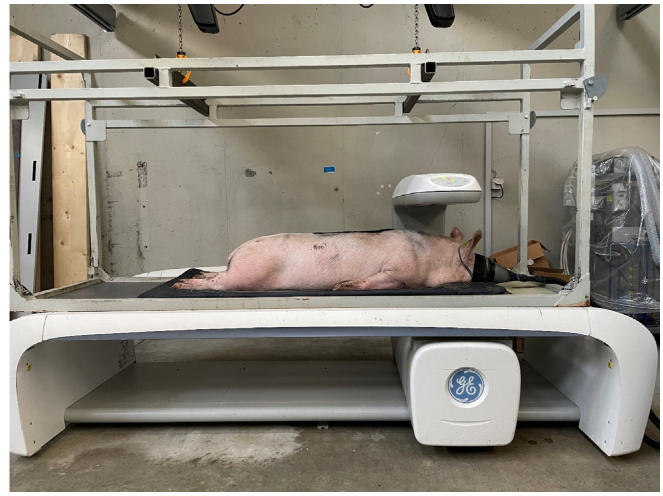

Fig. 2. Positioning of a ≥98 kg live finishing pig on the dual-energy X-ray absorptiometry (DXA) apparatus during scanning under anaesthesia to obtain the empty body's water, ash, protein, fat, and energy contents.

Calculations and statistical analysis

All data were analysed using the MIXED procedure of SAS (version 9.4, SAS Institute, Cary, NC, USA). The model included the dietary treatments as the fixed effect and the litter as a random effect. The fixed effects of feeding treatment are presented as least-square means. Multiple mean comparisons for the feeding treatment were performed with the PDIFF option and the Tukey adjustment. The effects were considered significant at $P \leq 0.05$ and a tendency at $0.05 > P \leq 0.10$. The acid-insoluble ash concentrations of the diets and the faeces were used to calculate the ATTD (%) using the following Eq. (1) from Jang et al. (2014):

$$ATTD_N = 100 - \left[100 \times \frac{IM_{feed}}{IM_{feces}} \times \frac{N_{feces}}{N_{feed}}\right] \quad (1)$$

where IM is the indigestible marker (celite®), and N is the nutrient of interest (i.e., gross energy, crude fibre, and CP in this experiment). Both IM and N are expressed in g/kg.

Results

Dietary effects on growth performance, apparent total tract digestibility, and feeding behaviour

All animals remained in good health throughout the entire experimental period. Of all the studied growth performance traits, only the FCR in the growing (but not the finishing) period significantly differed among treatments (Table 2). In the growing period,

Table 2
The growth performance of growing-finishing pigs offered *ad libitum* access to an unsupplemented standard growing and finishing diet (ST) or growing and finishing diets supplemented with 30% of salty (SA) or sugary (SU) former food products.

Item	Dietary treatments[1]			SEM	Effect
	ST	SA	SU		*P*-value[2]
BW at (kg)					
Start of the growing period	22.0	22.5	22.6	0.505	0.72
Start of finishing period	64.4	64.2	64.0	0.853	0.94
Slaughter	107.4	109.2	108.9	1.327	0.48
Average daily gain (kg/d)					
Growing period	0.91	0.88	0.86	0.021	0.26
Finishing period	0.95	0.95	0.96	0.028	0.98
Growing–finishing period	0.93	0.92	0.91	0.021	0.78
Average feed intake (kg/d)					
Growing period	1.82	1.84	1.79	0.059	0.68
Finishing period	2.71	2.70	2.75	0.053	0.79
Growing–finishing period	2.26	2.27	2.26	0.046	0.97
Feed conversion ratio					
Growing period	1.99[b]	2.09[a]	2.07[a]	0.024	0.005
Finishing period	2.85	2.84	2.90	0.041	0.61
Growing–finishing period	2.44	2.48	2.50	0.026	0.21
Days on feed in the					
Growing period	46.74	47.65	47.98	1.352	0.71
Finishing period	45.65	47.33	47.26	1.426	0.51
Growing–finishing period	92.21	94.93	95.31	1.753	0.34
Age at slaughter	160.9	163.8	162.1	2.729	0.52

[1] All growing and finishing diets were formulated based on the energy and nutrient requirements of pigs with a BW of 40 and 80 kg (Agroscope, 2022).
[2] *P*-value for the effect of the diet.
[a,b] Least square means with different superscripts differ ($P < 0.05$).

ST pigs were more ($P < 0.05$) efficient, as they displayed numerically greater ADG but did not ingest more feed than SA and SU pigs.

In both the growing and finishing periods, the energy digestibility of the SA diets was greater ($P < 0.05$) than that of the ST diets, with intermediate values for the SU diets (Table 3). In the finishing but not the growing period, the crude fibre digestibility of the ST diet was greater ($P < 0.05$) than that of the SA and SU diets. The CP ATTD did not differ among the groups.

The monitored feeding behaviour suggested that, during the growing period, pigs fed the SU growing diet had a greater ($P < 0.05$) number of feeder visits per meal than those fed the ST growing diet, with intermediate values for the pigs fed the SA growing diet (Table 4). During the finishing period, the pigs fed the ST finishing diet spent more time per visit ($P < 0.05$) at the feeder than those fed the SA finishing diet, with intermediate values for SU pigs. The feed intake per visit was greater in the finishing period of the ST pigs than that of the SA and SU pigs. No statistically significant differences were found between groups regarding the rate of feed intake (g/min) and eating behaviours, such as the total time spent feeding per day, frequency of feeder visits, or interval time between two meals.

Dietary effects on live body composition of pigs at 20 and 100 kg BW

The empty body water, ash, lipids, CP, and gross energy contents at the start of the experiment and one week before slaughter were similar for ST, SA, and SU pigs (Table 5). Total feed, CP and DE intake between the two DXA measurements were not statistically different among the treatment groups (Table 6). Only total dietary fat intake differed ($P < 0.05$) and was highest in SU and lowest in ST and intermediate in SA pigs. This reflected the differences in the fat content of the diets. Nevertheless, no significant differences were found in the pigs' empty body nutrient and energy deposition rate or in their protein and energy deposition efficiency (Table 6).

Dietary effects on carcass composition and quality traits

The three dietary treatments had no significant impacts on the carcass quality traits, except for the backfat thickness at the 10th rib level from the belly side (Table 7). The pigs fed the SU diet had the thickest belly fat compared to those who received the SA and ST diets ($P < 0.05$, Table 7).

Table 3
The apparent total tract digestibility (ATTD) of gross energy, crude fibre, and CP of the unsupplemented standard growing and finishing diets (ST) and the growing and finishing diets supplemented with 30% of salty (SA) and sugary (SU) former food products fed to growing-finishing pigs.

Item[2]	Dietary treatments[1]			SEM	Effect
	ST	SA	SU		*P*-value[3]
Gross energy ATTD (%)					
Growing period	81.80[a]	83.50[b]	82.60[ab]	0.398	0.01
Finishing period	82.70[a]	83.80[b]	82.90[ab]	0.415	0.03
Crude fibre ATTD (%)					
Growing period	39.00	38.40	40.40	2.070	0.66
Finishing period	39.50[b]	35.50[a]	34.70[a]	1.473	0.008
CP ATTD (%)					
Growing period	78.50[a]	80.20[b]	78.40[a]	0.534	0.04
Finishing period	79.40	80.70	79.70	0.635	0.24

[1] All growing and finishing diets were formulated based on the energy and nutrient requirements of pigs with a BW of 40 and 80 kg (Agroscope, 2022).
[2] The digestibility trial was conducted with 24 pigs (eight pigs from each treatment) in the middle of both the growing (≥40 kg BW) and the finishing period (≥80 kg BW). Faeces samples were collected from each pig in the morning from 08:00 on four consecutive days and subsequently pooled per pig for further analysis.
[3] *P*-value for the effect of the diet.
[a,b] Least square means with different superscripts differ ($P < 0.05$).

Table 4
Feeding behaviour of growing-finishing pigs offered *ad libitum* access to a standard growing and finishing diet (ST) or to growing and finishing diets supplemented with 30% of salty (SA) or sugary (SU) former food products.

	Dietary treatments[1]				Effect
Item	ST	SA	SU	SEM	*P*-value[2]
Total time spent feeding per day (min)					
Growing	66	70	68	4.028	0.71
Finishing	60	62	62	2.191	0.71
Number of daily meals					
Growing	9.2	9.9	10.3	0.707	0.28
Finishing	4.7[xy]	5.9[y]	5.2[x]	0.408	0.06
Number of feeder visits during one meal					
Growing	10.7[a]	12.1[ab]	14.1[b]	0.970	0.02
Finishing	5.3	6.7	5.9	0.508	0.16
Time spent at the feeder per visit (min)					
Growing	7.4	7.2	6.7	0.373	0.26
Finishing	13.3[b]	10.8[a]	12.4[ab]	0.777	0.03
Feed intake per visit (g)					
Growing	205	196	177	14.990	0.21
Finishing	612[b]	480[a]	554[a]	42.240	0.04
Rate of feed intake (g/min)					
Growing	28	27	27	1.320	0.79
Finishing	46	45	45	2.370	0.71
Interval between two meals (min)					
Growing	84	78	72	5.310	0.13
Finishing	135	113	123	7.860	0.11

[1] All growing and finishing diets were formulated based on the energy and nutrient requirements of pigs with a BW of 40 and 80 kg (Agroscope, 2022).
[2] *P*-value for the effect of the diet.
[a,b] Least square means with different superscripts differ ($P < 0.05$).
[x,y] Least square means with different superscripts differ ($P < 0.10$).

Table 5
Empty BW, nutrient, and energy content of the empty body determined by Dual-energy X-ray absorptiometry (DXA) at the start (measurement 1) of the experiment and one week before the slaughter (measurement 2) of growing-finishing pigs offered *ad libitum* access to an unsupplemented standard growing and finishing diet (ST) or growing and finishing diets supplemented with 30% of salty (SA) or sugary (SU) former food products.

		Dietary treatments[1]				Effect
Item[2]	Measurement[3]	ST	SA	SU	SEM	*P*-value[4]
Empty BW (kg)	1	22.9	23.3	23.3	0.290	0.83
	2	107.5	107.7	109.0	0.530	0.49
Empty body nutrient and energy composition						
Water (kg)	1	16.03	16.37	16.29	0.195	0.76
	2	63.73	63.15	64.16	0.386	0.59
Ash (kg)	1	0.68	0.68	0.69	0.008	0.89
	2	2.84	2.83	2.87	0.027	0.92
CP (kg)	1	3.55	3.65	3.63	0.057	0.76
	2	17.54	17.37	17.66	0.113	0.59
Lipids (kg)	1	2.22	2.18	2.22	0.038	0.91
	2	21.92	22.92	22.84	0.324	0.41
Gross energy content (MJ)	1	178.00	180.00	180.00	2.880	0.96
	2	1 314.00	1 348.00	1 353.00	12.100	0.39

[1] All growing and finishing diets were formulated based on the energy and nutrient requirements of pigs with a BW of 40 and 80 kg (Agroscope, 2022).
[2] Empty BW is defined as the BW without intestinal content.
[3] 1: pigs were DXA scanned × days after they reached at the weekly weighing a BW of ≥20 kg BW; 2: pigs were DXA scanned when at the weekly weighing they reached ≥98 kg BW, which was one week before the slaughter.
[4] *P*-value for the effect of the diet.

Discussion

The primary goal of the present study was to investigate the potential impact of sugar and salty FFPs on the growth performance, diet digestibility, and empty body and carcass composition of growing and finishing pigs. Previous studies (Tretola et al., 2019a; Luciano et al., 2021) have shown that FFPs do not negatively impair growth performance and diet digestibility in the post-weaning phase. The current results confirm and extend the existing data showing that feeding sugary or salty FFPs even at high dietary inclusion levels for a long period such as the growing-finishing diet has only minimal impact on the aforementioned traits.

Dietary effects on growth performance

The profitability of pig production is affected by the efficient use of feed for lean tissue growth and growth rate (Njoku et al., 2015). On the one hand, it is important to encourage the transition to more sustainable pig production systems; on the other hand, there is a need to ensure that the alternative feeding system does not impair the growth performance, carcass composition and feeding behaviour of the animals. In the current study, when considering the entire growing–finishing period, the use of FFPs did not affect the growth performance of the pigs. In particular, ADFI, ADG, and FCR were similar among the three groups. Similarly, in other studies in which different types of alternative feed ingredients were

Table 6
Total feed, CP and DE intake, daily nutrient and energy deposition rate in the empty body, and CP and energy deposition efficiency from the start to one week before the slaughter of growing-finishing pigs offered *ad libitum* access to an unsupplemented standard growing and finishing diet (ST) or growing and finishing diets supplemented with 30% of salty (SA) or sugary (SU) former food products.

Item[2]	Dietary treatments[1] ST	SA	SU	SEM	Effect *P*-value[3]
Total intake					
Feed (kg)	191.35	197.40	197.66	1.450	0.23
CP (kg)	29.30	30.19	30.20	0.220	0.27
Fat (kg)	9.15[a]	20.47[b]	11.73[c]	0.180	0.001
DE (MJ)	2 622.00	2 704.00	2 708.00	20	0.23
Daily gain					
Empty body (g/d)	989.00	955.00	965.00	10	0.47
Water (g/d)	558.00	529.00	539.00	6	0.23
Ash (g/d)	25.00	24.00	25.00	0.40	0.65
Lipid (g/d)	230.00	235.00	233.00	4	0.91
CP (g/d)	164.00	155.00	158.00	2	0.23
Gross energy (MJ/d)	13.30	13.20	13.20	0.20	0.99
Deposition efficiency[4]					
CP (%)	47.90	45.50	46.50	0.499	0.17
Energy (%)	43.30	43.20	43.30	0.274	0.98

Abbreviations: DE = digestible energy.
[1] All growing and finishing diets were formulated based on the energy and nutrient requirements of pigs with a BW of 40 and 80 kg (Agroscope, 2022).
[2] Feed, CP and DE intake were determined between the start of the experiment and one week before the slaughter. The average daily weight gain of the empty body, nutrients and energy in the empty body was calculated from the respective dual-energy X-ray absorptiometry values presented in Table 4.
[3] *P*-value for the effect of the diet.
[4] $\text{CP efficiency} = \frac{\text{total CP deposition in the empty body}}{\text{total CP intake}}$; $\text{Energy efficiency} = \frac{\text{total energy deposition in the empty body}}{\text{total DE intake}}$.
[a,b,c] Least square means with different superscripts differ ($P < 0.05$).

Table 7
Characteristics of carcasses from growing-finishing pigs offered *ad libitum* access to an unsupplemented standard growing and finishing diet (ST) or growing and finishing diets supplemented with 30% of salty (SA) or sugary (SU) former food products.

Items[2]	Dietary treatments[1] ST	SA	SU	SEM	Effect *P*-value[3]
Hot carcass weight (kg)	85.5	86.5	86.3	0.75	0.62
Carcass yield (%)	79.7	79.3	79.2	0.52	0.36
Carcass length (cm)	97.0	97.0	97.0	1	0.97
Backfat thickness at					
10th rib level (mm)	25.0	26.0	25.0	0.90	0.38
10th rib level, belly side (mm)	20.0[a]	21.0[ab]	23.0[b]	0.90	0.02
Lean meat (%)	54.2	53.6	53.1	0.44	0.23
Loin (%)	24.7	24.3	24.2	0.24	0.33
Ham (%)	18.2	17.9	17.6	0.24	0.31
Shoulder (%)	11.3	11.3	11.3	0.16	0.96
Belly portion (%)	20.4	20.4	20.6	0.19	0.74
Backfat (%)	12.4	12.7	12.8	0.25	0.39
Loin fat (%)	6.8	7.1	7.2	0.18	0.39
Ham fat (%)	18.2	17.9	17.6	0.24	0.31
Shoulder (%)	11.3	11.3	11.3	0.16	0.96
Leaf fat (%)	1.4	1.5	1.5	0.07	0.59

[1] All growing and finishing diets were formulated based on the energy and nutrient requirements of pigs with a BW of 40 and 80 kg (Agroscope, 2022).
[2] Lean meat (%): sum of denuded loin, shoulder, and ham weights as percentage of the cold carcass weight; loin, ham and shoulder (%) are the weight of each portion expressed as percentage of the cold carcass weight; backfat (%): sum of the external fat from the loin, shoulder, and ham expressed as percentage of the cold carcass weight; loin fat, ham fat and shoulder fat are the weight of the external fat of each portion expressed as percentage of the cold carcass weight.
[3] *P*-value for the effect of the diet.
[a,b] Least square means with different superscripts differ ($P < 0.05$).

included (Fondevila et al., 2021; Hilbrands et al., 2021) or different rearing phases were considered (Tretola et al., 2019a; Tretola et al., 2019b; Hilbrands et al., 2021; Luciano et al., 2021), co-products did not represent any issue for the growth when well-balanced diets covering the pig's nutrient requirement were provided. By contrast, the present study showed that FCR was affected by the diets only in the growing period. Specifically, pigs fed the ST growing diet had a lower FCR than those fed the SA (+4.5%) and SU (+4.0%) growing diets, even though the number of days on feed, total feed intake, and ADFI did not differ among the groups in the same period. Luciano et al. (2022) reported similar findings in their study. In newly weaned pigs, including high bakery meal into the diet (substitution rate of corn from 25 to 100%) reduced the feed efficiency of the pigs. In that study, the immaturity of the gut was reported as a possible explanation for this effect (Luciano et al., 2022). Therefore, we speculate that the detrimental effect on the FCR in the growing period, but not the finishing period, could be related to the time needed to the animal for adapting the gut to the diet. It is well known that animals need time to adapt to changes in nutrient availability (Enriquez et al., 2022; Luciano et al., 2022). These adaptation to a substantial change in diet, including whole-body metabolism and tissue functional and morphologic changes, as well as single-cell transcriptomics can be very quick at transcriptional level, but relatively slow for intestinal epithelium adaptations to maximise absorption of selected nutrients (Enriquez et al., 2022). This type of intestinal plasticity may be an evolutionary adaptation to periods of nutrient scarcity but also to periods of specific nutrient excess such as simple sugars. Studies on rodents have demonstrated that a diet rich in simple sugars promotes a pro-inflammatory response and influences the gut mucosal barrier via gut microbiota (Fajstova et al., 2020). However, in the present study, we did not report the effects of simple sugars on gut health which could address better these transitory effects on FCR. Moreover, the lower feed efficiency observed in SA and SU compared to ST pigs could be partly explained by the numerical lower growth rate (SA: 30 g/d; SU: 50 g/d).

Dietary effects on digestibility

In the present study, the digestibility of energy, crude fibre and CP were affected by dietary treatments in different ways. Pigs fed the SA diet showed greater energy ATTD in both the growing and finishing periods compared to pigs fed the ST diet. However, the greater energy digestibility was not sufficient to positively impact the growth rate. In contrast, the crude fibre digestibility of the ST finishing diet was greater than that of the other finishing diets. The reasons for this are unknown, even though dietary features and time/interval can be considered as the main driving forces in the present study. From a dietary point of view, as reported by Pinotti et al. (2021), FFPs are usually characterised by high-energy and nutrient digestibility, which, based on their inclusion rate, can affect the digestibility of the complete diet (Luciano et al., 2022). In the early postweaning period, (Luciano et al., 2021) found a significant positive effect of salty ingredients on improving energy ATTD. It has been reported that carbohydrates and dietary fibres affect digestion and metabolic utilisation, not only due to the physicochemical properties but also because of the matrix in which the fibres are embedded (Jha et al., 2019). Thus, it can be speculated that, regarding GE ATTD, both the SA and SU diets were more digestible compared to the ST diet; however, the SA diet showed the highest value of digestibility. These results can be linked to the presence of highly processed materials in both sugary and salty FFPs. Processing technologies, such as mechanical forces (pressure, shear, attrition, abrasion) and thermal and chemical modifications of the feedstuff, lead to the breakage of feed particles. In this way, the seed coat is broken, the particle size and fibre length are reduced, and the cell wall structure is broken. Moreover, during thermal processes, the weak polysaccharides–gly cosidic linkages within polysaccharides can be broken. In starch-rich products, heating, particularly under moist conditions, causes starch gelatinisation. This causes the cell to swell and break, thus increasing the surface area of the cell and disrupting the cellular integrity (De Vries et al., 2012). The differences in GE digestibility observed with the SA and SU diets compared to the ST diet can be related to a combination of several factors, such as the type of carbohydrates, the way through which the starch is processed, content and the type of fibre fractions. For example, FFPs are rich in processed starch instead of resistant starch, and the latter has been associated with low digestible energy and energy retention in pigs (Gerrits et al., 2012). Starch, being the dominant nutrient in pig diets, strongly influences digesta transit in the gastrointestinal tract, as observed in pigs fed extruded or ground cereals (Martens et al., 2019). To reach a similar crude fibre content in the three growing and finishing diets, the SA and SU diets had a 4% higher amount of wheat bran compared to the ST diet. However, the SA and SU diets had still a slightly lower crude fibre level. This slightly lower crude fibre content of the SA and SU diets compared to the ST diet could have resulted in a better ATTD of the FFPs-based diets. To note that compared to the ST group, pigs fed the SA diet had a better ATTD of GE and CP in the growing period and a better ATTD of GE and crude fibre in the finishing period. Zhao et al., (2018) showed how increasing levels of fibres linearly decreased the ATTD of the diets fed to growing pigs. Despite the greater ATTD values, no differences in the growth performance were observed between the SA and ST pigs and the ST pigs displayed even greater feed efficiency values compared to the SA pigs in the growing period. A possible explanation could be related to the high sodium chloride content of the SA diet. Despite the better ATTD values, the high intake of sodium chloride in the SA group could have led to a hypertonic luminal content in the intestine. This could have resulted in an increased intestinal motility (Norris, 1973) and a subsequent reduction of energy procurement from food (Zhi et al., 2019) explaining the lack of significant differences in growth performance between the treatment groups. Another explanation could be related to the differences when ATTD and FCR were assessed. The ATTD was determined at two specific time points, while the FCR reflects the efficiency of a pig during a longer period of time.

Dietary effects on feeding behaviour

In the present study, growing pigs fed the SU diets showed a significantly greater number of feeder visits per meal compared to those fed the ST diet, even though the feed intake per day and the feed intake per visit were not significantly different among groups. It has been shown that the sweet taste combined with the supply of nutrients enhances chewing behaviour in growing pigs (Day et al., 1996). Accordingly, Sterk et al. (2008) hypothesised that pig diets that include sweeteners can modulate the feeding behaviour of animals by increasing the number of visits to the feeder. As mentioned above, FFP undergoes processing that increases starch digestibility (De Vries et al., 2012). Pigs fed diets rich in rapidly digestible starch have shorter inter-meal intervals and meal durations (Da Silva et al., 2014) and greater activity-related energy expenditure (Bolhuis et al., 2008) than pigs fed slowly digestible or resistant starch. This is consistent with our results, which show that finishing pigs fed SA or SU FFPs spent less time at the feeder and ingested less feed per visit but tended to have a greater number of feeder visits compared to the pigs fed the ST diet. By contrast, no information is available for salty ingredients in pig diets. Despite the higher number of feeder visits and the higher feed intake per visit, the SA- and SU-fed pigs showed the same ADFI values as the ST group. Also, this result could be explained by the processed starch that characterises the FFPs, which when included at high level in a pig diet can affect the glycaemic index potential (Ottoboni et al, 2019), shortening the status of satiety (Bolhuis et al., 2008). These aspects however merit further investigations.

Dietary effects on body composition and carcass quality traits

The use of SU or SA FFPs in the pigs' diets had no effect on the content and deposition rate of nutrients and energy in the empty body. As diets were isoenergetic and isoproteic and the total feed intake was similar among treatments, protein and energy deposition efficiency did not differ. In contrast, the total fat intake was greatest in the SU pigs and lowest in the ST pigs. This difference was due to the difference in fat content between the diets, with the SU growing and finishing diets having the highest crude fat content, followed by the SA and then ST diet. However, the different fat intakes did not affect the average daily fat weight gain. Comparable to Realini et al.'s (2010) study, the higher fat content and saturated FAs in the pigs' diets did not significantly affect the fat-to-lean ratio of the carcasses. This finding suggests that the three groups of pigs were able to convert nutrients, especially different fat sources, into similar fat weights. Even if the sum of the external fat weights expressed as a percentage of the cold carcass weight was similar among the three groups, the fat cover on the belly at the 10th rib level was greater in carcasses of SU than in ST and SA pigs. This could be a result of a different distribution of body fat. One possible explanation could be related to the different fatty acid profiles in the diets. Although reported in other species, broilers fed a diet rich in polyunsaturated FAs showed a reduced fat deposition in the abdominal zone compared to those fed a diet rich in saturated fats (Crespo and Esteve-Garcia, 2002). A further hypothesis could be related to dietary sugars. It has been observed that FFPs are excellent carbohydrate sources that combine simple and complex sugars in the same food matrix (Ottoboni et al., 2019). The rate of fat deposition could have been affected by the simple sugar content of the SU diet. Furthermore, Konieczna et al. (2021) indicated that even the characteristics of industrially processed food (e.g., the breakdown of the food matrix in sweet snacks) influenced adiposity, for example, increasing the absorption and bioavailability of sugars, which then promoted fat accumulation. In pigs, glucose is the main source of substrate for de novo lipogenesis, and the major site for fat deposition is subcutaneous adipose tissue (Woods et al., 1974). In the current study, the observed thickest abdominal fat in the SU group is in line with the results obtained in rats by Bocarsly et al. (2010), where rats fed a diet supplemented with high-fructose corn syrup for a long term showed increased belly fat thickness, even though the total calorie intake was similar.

Although related to the fatty acid profile of subcutaneous adipose tissue, significant differences were found among postweaning piglets that received standard, sweet, and salty diets. The fat derived from carcasses of piglets fed a sugary diet had a lower polyunsaturated fatty acid concentration than the control group, thus suggesting that the inclusion of sugary FFPs may affect the characteristics of subcutaneous fat in pigs (Ottoboni et al., 2022). It is well known that fat deposition in adipose tissue strongly depends on the energy intake (Nürnberg et al., 1998). In agreement, Bee et al. (1999) showed that castrated-male pigs fed a low-energy diet deposited up to 23% less backfat resulting in a thinner backfat layer than those fed a high-energy diet. The results of this experiment confirm that FFPs can replace up to 30% of wheat in the diets of both growing and finishing pigs, with no detrimental effects on growth performance. The results showed that the diet supplemented with salty ingredients increased the energy digestibility in both the growing and finishing periods compared to the ST and SU diets, while crude fibre digestibility was lower in the SU and SA finishing diets than the ST finishing diet. Such results also demonstrate that FFPs do not affect nutrient deposition efficiency or the proportion of protein and fat in the carcass. However, abdominal belly fat was thicker in pigs that received the sugary FFP-based diet than in those fed standard and salty FFP-based diets. When the high levels of FFPs are included in diets covering the nutrient requirements, they could partially substitute conventional feed ingredients for pigs in the early, growing, and finishing phases. Despite this, further investigation of the effects of sugary FFPs on the thickness of belly fat is needed due to the commercial classification of carcasses. Moreover, evaluations of the potential effects that FFPs may have on meat quality, including its sensory aspects and chemical composition, need to be carried out. The present study only considered castrated-male growing-finishing pigs. Whether growing-finishing females will perform similarly when offered FFP-supplemented diets need to be tested in future studies.

Supplementary material

Supplementary material to this article can be found online at https://doi.org/10.1016/j.animal.2023.101019.

Ethics approval

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 Center in Posieux (Fribourg, Switzerland).

Data and model availability statement

None of the data were deposited in an official repository. The data that support the study findings are available from the authors upon request and after authorisation by all authors.

Declaration of Generative AI and AI-assisted technologies in the writing process

The authors did not use any artificial intelligence-assisted technologies in the writing process.

Author ORCIDs

S. Mazzoleni: https://orcid.org/0000-0002-8141-3442.
M. Tretola: https://orcid.org/0000-0003-3317-4384.
A. Luciano: https://orcid.org/0000-0003-0600-9498.
P. Lin: https://orcid.org/0000-0001-5351-2817.
L. Pinotti: https://orcid.org/0000-0003-0337-9426.
G. Bee: https://orcid.org/0000-0002-6397-7543.

Author contributions

S. Mazzoleni: Writing - Original Draft, Writing - Review & Editing, Investigation.
M. Tretola: Writing - Review & Editing, Investigation, Formal analysis, Data Curation.
A. Luciano: Investigation.
P. Lin: Investigation.
L. Pinotti: Writing - Review & Editing, Visualisation, Funding acquisition.
G. Bee: Writing - Review & Editing, Formal analysis, Supervision, Resources, Project administration.

Declaration of interest

None.

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