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Feeding Sows Lucerne, or Diets with Similar Energy and Nutritional Profiles to Lucerne, Improves the Pre-Weaning Performance of Piglets

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Abstract: Feeding fibre and branched-chain amino acids (BCAA) to sows during late gestation and lactation, respectively, have been shown to improve litter weights at weaning. Therefore, supplementing primiparous sow diets with lucerne chaff, a feedstuff high in fibre, BCAA and tryptophan, may improve the performance of their progeny. Experiment 1 investigated the effects of feeding primiparous sows (n = 118) either (i) a control diet (CON); (ii) CON with 1 kg of lucerne chaff (LUC); or (iii) a diet formulated to have a similar digestible energy and BCAA content as CON + LUC (SIMLUC 1) until farrowing. The LUC and SIMLUC 1 diets improved day 21 litter weight (p = 0.055). In Experiment 2 primiparous (n = 111) and multiparous sows (parities 2–5, n = 112) were fed either the CON or SIMLUC diet (SIMLUC 2) from day 110 of gestation to farrowing (PreF), or to day 10 post-farrowing (PreF + PostF). The SIMLUC 2 diet tended to be more beneficial to primiparous compared to multiparous sows when fed PreF, as indicated by an interaction between diet and parity on day 21 average piglet weights (p = 0.078). Overall, SIMLUC is most effective in improving primiparous progeny performance as evidenced by their D21 weights.

Keywords: gilt progeny; lucerne; primiparous sow; weaning weights

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1. Introduction

Progeny of the primiparous sow (gilt progeny; GP) are often characterised by their low birth and weaning weights, slow growth and higher rates of morbidity and mortality in comparison to those from multiparous sows (sow progeny; SP) [1–3]. Collectively, this culminates in a longer time to reach optimal market weight and, ultimately, reduced revenue for the producer. In order to mitigate this issue, the growth of GP must be supported during the pre-weaning period. A study by Craig et al. [4] showed that colostrum and milk profiles were similar between primiparous and multiparous sows, suggesting that GP growth is largely attributed to a lack of milk production rather than differences in composition. Therefore, GP may benefit from strategies that increase milk production in the primiparous sow to support the growth of GP in the pre-weaning period.

The inclusion of dietary fibres in late gestation diets has been reported to increase feed intake of sows during lactation, and is mostly attributed to the effects on the gastrointestinal capacity of the dam [5]. For example, Quesnel et al. [6] reported an increased feed intake and piglet weight at weaning in primiparous sows when fed a diet containing 12.4% crude fibre, which increased the content of both soluble and insoluble fibres, between day 26 of gestation and farrowing. Rooney et al. [7] reported increasing soluble fibre content, in the form of sugar-beet pulp, increased live weight and carcass muscle depth of GP. Moreover, some forms of dietary fibre have been shown to have beneficial impacts on behaviour and welfare of gestating sows. Edwards et al. [8] reported an improvement in sow welfare during farrowing and throughout lactating when 1 kg of lucerne chaff, a soluble fibrous forage also high in branch-chained amino acids (BCAA), and tryptophan, was given daily.

Branched-chain amino acids have been shown to change milk composition of the lactating sow by increasing the dietary protein and BCAA contents, but not milk yield [9]. Furthermore, Zhao et al. [10] found that increasing the dietary concentrations of valine during late gestation and lactation resulted in improved colostrum lactose and IgG concentrations and increased piglet growth rate during lactation. The inclusion of lucerne in late gestation diets due to its high soluble fibre and high BCAA concentrations may collectively improve the growth rate and survival in GP. However, feeding supplemental lucerne may present difficulties in effluent management, cost, quality, and biosecurity issues; alternative dietary strategies that provide a similar nutrient intake to lucerne may be useful. Therefore, the presented studies aimed to determine whether supplementation of late gestation and lactation diets with lucerne, or diets with similar digestible energy and BCAA profiles, can maximise GP growth performance.

2. Materials and Methods

The two experiments were conducted under commercial conditions at a commercial piggery in South Australia (SunPork Pty Ltd., Wasleys, SA, Australia) in April 2018 and September 2019.

2.1. Ethics Statement

All experimental procedures were approved by the Primary Industries and Regions South Australia (PIRSA) Animal Ethics Committee (license number 247 and approval number 09-19) under the Southern Australian Animal Welfare Act, in accordance with the Australian Code for the Care and Use of Animals for Scientific Purposes (National Health and Medical Research Council, 2013).

2.2. Experiment 1

Animals, Diets and Experimental Design

The study involved 118 Large White × Landrace (PIC Cranborough 42) primiparous sows serviced with pooled semen. The sows were fed one of three dietary treatments in late gestation and during lactation. The three diets offered were: a commercial primiparous sow lactation diet (CON, $n = 43$) offered at 2.5 kg/day; the CON diet plus 1 kg/day of Lucerne chaff, delivered at the same time to a separate part of the feeder (LUC, $n = 33$); or 3.5 kg/day of a diet formulated to have a similar digestible energy (DE), BCAA and tryptophan concentration as the combined CON and LUC diet (SIMLUC 1, $n = 42$) (Table 1). All diets were fed from day 108 of gestation (108 ± 0.1; mean ± SE). The diets continued to be fed ad libitum for the first 3 days of lactation, after which time all primiparous sows received the CON diet ad libitum until weaning. The primiparous sows were housed in farrowing crates fitted with nipple drinkers for both sow and piglets, with piglets having access to a heat lamp in the creep area. Piglets were cross fostered to sows rearing ability (number of functional teats). Minimal fostering was practiced and fostering was conducted within parity and diet when possible. The number of piglets born alive (BA), stillborns (SB) and mummified foetuses were recorded for each litter. Litters were weighed again at 21 days. Pre-weaning mortalities were also recorded. The lucerne chaff was cut after budding and was estimated to contain 18% crude protein and 27% crude fibre. The SIMLUC 1 diet was formulated to have similar but not identical nutritional profiles to a combination of the 2.5 kg of the CON diet plus 1.0 kg of lucerne, and was formulated from readily available ingredients. The major changes were a decrease in wheat and an increase in barley and millrun, a by-product of flour that is high in fibre. The SIMLUC1 diet aimed to provide similar concentrations of DE, BCAA and tryptophan to the CON + LUC diet;

other differences in fibre composition, and vitamin and mineral intakes were not controlled. Feed intake was not recorded.

Table 1. Composition of experimental diets fed in late gestation and 3 days after farrowing (% as fed) in Experiment 1.

Ingredients	CON	SIMLUC 1	LUC
Barley	0	39	
Wheat	46.8	10	
Millrun	12.7	21.9	
Field Peas	5.2	0	
Canola Meal	10	12	
Full Fat Soyabean	1.1	0	
Blood Meal	2	0	
Meat Meal	5.3	3	
Salmate Oil	0.4	0.4	
Vegetable Oil Blend	3.5	1	
Limestone	0.42	0.97	
Monocalcium Phosphate	0	0.4	
Betaine Liquid 40%	0.6	0.3	
Lactation Concentrate Mash	12	6	
Pre-farrow Concentrate mash	0	5	
Estimated composition			
Energy (MJ DE/kg)	14.3	12.8	7.5
Crude Protein (%)	21.2	17.4	18.0
Crude Fibre (%)	4.50	6.30	27.0
Ash (%)	5.3	5.9	9.5
Available SID lysine (%)	1.05	0.72	0.44
Tryptophan:Lysine (%)	0.20	0.25	0.36
Isoleucine (%)	0.77	0.73	0.71
Leucine (%)	1.57	1.19	1.28
Valine (%)	1.07	1.11	0.8
Total available BCAA (%)	3.41	3.03	2.79
Total available BCAA:SID lysine (%/%)	3.24	4.21	6.34

2.3. Experiment 2

2.3.1. Animals, Diets and Experimental Design

A total of 223 Large White × Landrace sows comprising 111 primiparous and 112 multiparous sows (parities 2–5 sows) were serviced with pooled semen for Experiment 2. A 2 × 3 factorial arrangement of treatments was used. Primiparous and multiparous sows were allocated to one of three dietary treatments (Table 2): (i) a standard commercial lactation diet fed until farrowing (control; CON) at 2.5 kg/day and then ad libitum to weaning; (ii) SIMLUC 2 fed until farrowing (pre-farrowing; PreF) at 5 kg/day, and then the CON diet fed ad libitum to weaning; (iii) a SIMLUC 2-supplemented diet fed at 5 kg/day to farrowing, then ad libitum until day 10 after farrowing, and then the CON diet ad libitum to weaning (post-farrowing; PreF + PostF) (Figure 1). The SIMLUC 1 diet used in Experiment 1 was reformulated based on commercially available ingredients to make SIMLUC 2 because there were seasonal differences in the availability of ingredients and the nutrient content of available ingredients. The CON diet was fed at 0700 and SIMLUC 2 was split-fed at 0700 and 1500. Feeding of all diets commenced upon entry of sows to the farrowing house at day 110 of gestation. Feed intake was not recorded. Between farrowing and day 1, two sows and one gilt died, and two gilts and two sows were removed from the trial because they were not milking.

Table 2. Composition of experimental diets fed in late gestation and lactation (% as fed) in Experiment 2.

Ingredients	CON	SIMLUC 2
Barley	15.6	35.4
Wheat	41. 9	19.7
Millrun	6.5	25
Field Peas	7.5	0
Lentils	2.55	1.5
Canola Meal	7.15	2.15
Soyabean Meal	0	3.5
Blood meal	0.8	0.7
Meat meal	6.2	1.9
Salmate Oil	0.4	0.4
Vegetable Oil Blend	3.25	0.8
Limestone	0.62	1.26
Monocalcium phosphate	0	0.37
Betaine Liquid 40%	0.48	0.40
Breeder concentrate mash	2	4
Lactation concentrate mash	5	0
Pre-farrow concentrate mash	0	3
Estimated composition		
Energy (MJ DE/kg)	14.1	12.6
Crude Protein (%)	18.3	16.1
Crude Fibre (%)	4.51	6.18
Ash (%)	5.03	5.55
Available SID lysine (%)	0.85	0.70
Tryptophan:Lysine (%)	0.19	0.26
Isoleucine (%)	0.66	0.69
Leucine (%)	1.27	1.09
Valine (%)	0.89	1.06
Total available BCAA (%)	2.82	2.85
Total available BCAA:SID lysine (%/%)	3.33	4.07

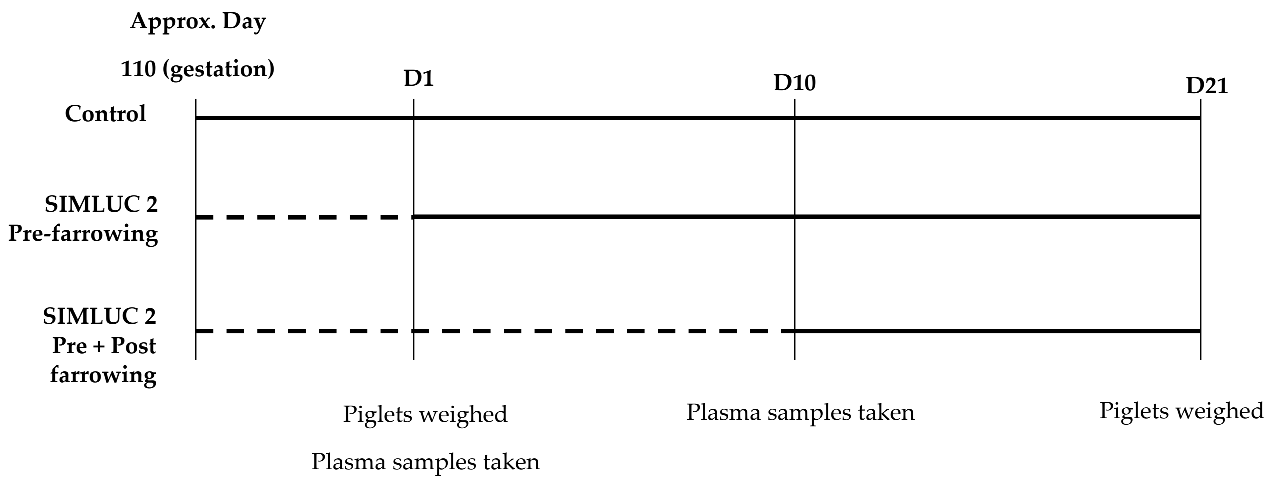

Figure 1. Timeline of diets and measurements taken at day 1 (D1), day 10 (D10), and day 21 (D21) after farrowing. Dashed line indicates feeding of SIMLUC 2 and solid line CON diets.

Piglets were weighed at day 1 (D1) of age and individually ear-tagged (n = 2677). Farrowing performance was assessed by the total piglets born (TB), BA, SB and mummified (MU) piglets recorded for each litter. A sub-sample of piglets (n = 1578) were weighed on day 21 (D21) to ascertain pre-weaning growth rates. The number of piglets weaned, removals for ill thrift and pre-weaning mortalities were recorded. Piglets were cross fostered using the same criteria as those of Experiment 1.

2.3.2. Blood Sample Collection

Individual blood samples were taken from the sows at D1 and D10 after farrowing ($n = 72$) (Figure 1). Individual piglet blood samples were also taken from two piglets per litter (one male and one female, $n = 144$) at D1 and D10 from the external jugular vein into lithium heparin Vacutainers®® tubes (BD Australia, North Ryde NSW, Australia) using a 21-gauge needle. Tubes were then inverted to ensure mixing with anti-coagulant and placed on ice. Plasma was collected following centrifugation at $1500\times g$ for 10 min then stored at −20 °C until analysis.

2.3.3. Metabolite Analysis

Plasma samples were assayed for glucose, urea, protein (catalogue nos. TR15221, TR12421 and 23200, respectively, Thermo Fisher Scientific, Middletown, MA, USA), non-esterified fatty acids (NEFA-C, catalogue no. 27975401, Wako Pure Chemical Industries, Osaka, Japan) and BCAA (catalogue no. ab83374, Abcam, Cambridge, NY, USA) concentrations. All assays were carried out as per the manufacturers' instructions, with the exception of NEFA, which was performed by diluting reagent A with 0.05 M phosphate buffer (pH 6.9) and B with purified water. The intra- and inter-assay variations (%CV), respectively, were 1–7% and 7–8% for glucose, 1–4% and 3% for NEFA, 1–3% and 2% for urea, 2–5% and 5% for protein, and 0.1–2.3% and 4% for BCAA.

2.4. Statistical Analyses

All data were analysed using Genstat (16th edition). Linear mixed models were used for growth and metabolite data. For analysis of Experiment 1, diet (control vs. LUC vs. SIMLUC 1) was allocated as the main factor and room allocated as the random term. The litter size on D1 and the number of days on diet prior to farrowing were fitted as covariates when a significant contribution to the model was made. For Experiment 2, analysis of litter data was performed by designating parity (primiparous vs. multiparous) and diet (CON vs. PreF vs. PreF + PostF) as the main and interactive factors, whereas room was designated as the random term. For D1 sow and piglet metabolite data in Experiment 2, parity (primiparous vs. multiparous) and diet (CON vs. SIMLUC2) were allocated as the main and interactive factors, whereas for D10 sow and piglet metabolite data, parity (primiparous vs. multiparous) and diet duration (CON vs. PreF vs. PreF + PostF) were allocated as the main and interactive factors. For sow metabolite analysis, room was designated as the random term, whereas for piglet metabolite analysis, individual sow was designated as the random term. The number of days on diet prior to farrowing was fitted as a covariate for all analysis when a significant contribution to the model was made. Pre-weaning mortality data were analysed using a generalised linear mixed model with a Poisson distribution with sow as the experimental unit and mortalities expressed as mortalities/litter. Other data are presented as mean ± standard error of the difference (SED). A value of $p < 0.05$ was used to indicate statistical significance and a value of $p < 0.10$ was considered a statistical trend.

3. Results

3.1. Experiment 1

Litters born to sows on the CON diet tended to have lower D21 litter weights than LUC and SIMLUC 1 (48.1 vs. 53.4 and 53.7 kg, respectively, $p = 0.055$) (Table 3). Average piglet weights were lower when born to sows fed the CON diet than those fed the LUC and SIMLUC 1 diets (4.69 vs. 4.89 and 5.12, respectively, $p = 0.029$) at D21 (Table 3). Furthermore, litters of the CON diet grew slower than litters born to the LUC and SIMLUC 1 diets (1.80 vs. 2.10 and 2.06 kg, respectively, $p = 0.031$) during the pre-weaning period. There were no other significant main or interactive effects (Table 3).

Table 3. Litter performance of primiparous sows fed a control diet (CON), lucerne (LUC), or a diet formulated to have similar DE, BCAA and tryptophan concentration as lucerne (SIMLUC 1).

Parameter	CON	LUC	SIMLUC 1	SED	*p*-Value
n	43	33	42		
Total born	14.1	13.9	13.9	0.342	0.77
Born alive	13.7	13.4	13.5	0.341	0.77
Stillborn	0.42	0.43	0.41	0.170	0.96
D1 litter size	12.1	11.9	12.2	0.217	0.37
D1 total litter weight (kg)	14.6	14.8	14.9	0.465	0.86
D1 average piglet weight (kg)	1.21	1.24	1.22	0.032	0.38
D21 litter size	10.0	10.7	10.4	0.386	0.19
D21 total litter weight (kg)	48.1^{a}	53.4^{ab}	53.8^{b}	2.687	0.055
D21 average piglet weight (kg)	4.69^{a}	4.89^{ab}	5.12^{b}	0.170	0.029
Litter ADG (kg/day)	1.80^{a}	2.10^{b}	2.06^{b}	0.125	0.031
Litter size weaned	10.0	10.3	10.5	0.391	0.40
Mortality (pigs/litter)	0.53 (1.69)	0.24 (1.25)	0.32 (1.38)	0.14	0.30

[a,b] Within a row, values not having the same superscript are significantly different.

3.2. Experiment 2

3.2.1. Pre-Weaning Performance

Primiparous litters were lighter than multiparous sow litters on D1 (14.9 vs. 16.2 kg, $p < 0.001$) and individual GP were lighter on average compared to SP (1.26 vs. 1.39 kg, $p < 0.001$) (Table 4). At D21, primiparous sows had smaller litter sizes than multiparous sows (9.31 vs. 9.99, $p = 0.013$) (Table 4). Sows fed the CON and SIMLUC 2 PreF diets had larger litters at D21 compared to those fed SIMLUC 2 PreF + PostF (9.72 vs. 10.1 vs. 9.15, respectively, $p = 0.024$) (Table 4). Primiparous litters were lighter than multiparous sow litters at D21 (45.6 vs. 58.3, $p < 0.001$) (Table 4). Sows fed the CON and SIMLUC 2 PreF diets had heavier litters at D21 than those fed SIMLUC 2 PreF + PostF (53.3 vs. 54.1 vs. 48.6 kg, respectively, $p = 0.019$) (Table 4). The GP were lighter on average compared to SP at D21 (4.88 vs. 5.85 kg, $p < 0.001$) (Table 4). Furthermore, an interaction between parity and diet was observed such that GP from primiparous sows fed SIMLUC 2 PreF + PostF tended to be the lightest of all groups, and SP of the CON diet tended to be the heaviest of all groups ($p = 0.078$) (Table 4). Primiparous litters grew slower than multiparous sow litters during the pre-weaning period (1.68 vs. 2.10, $p < 0.001$) (Table 4). Furthermore, sows fed the CON and SIMLUC 2 PreF diets had faster-growing litters compared to those on the SIMLUC 2 PreF + PostF diet (1.99 vs. 1.92 vs. 1.76 kg/day, respectively, $p = 0.05$) (Table 4). An interaction between parity and diet was observed on ADG where primiparous sow litters fed the SIMLUC 2 PreF + PostF diet tended to have the slowest growing litters, whereas sows fed the CON diet tended to have the fastest-growing litters ($p = 0.098$) (Table 4). Primiparous litters had the highest pre-weaning mortality compared to sow litters (3.11 vs. 2.42, $p = 0.018$).

Table 4. Litter performance of primiparous and sows fed either a commercial control diet (CON) or the SIMLUC 2 diet fed either pre-farrowing (PreF) or pre- and 10 days post-farrowing (PreF + PostF).

Parity (P)	Primiparous			Multiparous			SED	*p*-Value		
Diet (D)	CON	PreF	PreF + PostF	CON	PreF	PreF + PostF		P	D	P × D
n	34	38	39	44	31	37				
Total born	12.4	12.2	11.9	12.0	13.1	12.5	0.720	0.48	0.57	0.38
Born alive	11.6	11.7	11.3	11.1	12.4	11.7	0.691	0.78	0.36	0.42
Stillborn	0.76	0.53	0.64	0.85	0.74	0.79	0.260	0.30	0.66	0.94
Mummified	0.23	0.08	0.35	0.29	0.26	0.25	0.134	0.54	0.31	0.32
n	33	38	39	43	31	36				
D1 litter size	11.8	11.9	11.9	11.6	11.8	11.6	0.26	0.15	0.61	0.93
D1 total litter weight (kg)	14.8	15.2	14.7	16.1	16.1	16.5	0.64	<0.001	0.53	0.99
D1 average piglet weight (kg)	1.26	1.27	1.24	1.39	1.40	1.38	0.05	<0.001	0.78	0.99
D1 litter CV (%)	18.3	19.4	16.7	18.7	20.7	18.8	1.79	0.22	0.17	0.79
n	28	26	32	35	21	33				
D21 litter size	9.37	9.92	8.65	10.1	10.3	9.64	0.488	0.013	0.024	0.68
D21 total litter weight (kg)	45.8	50.0	41.1	60.9	57.9	56.2	3.041	<0.001	0.019	0.19
D21 average piglet weight (kg)	4.86	5.03	4.74	6.07	5.66	5.84	0.184	<0.001	0.30	0.078
D21 litter CV (%)	18.2	19.4	18.7	18.1	19.2	19.3	0.019	0.94	0.65	0.94
D1 to D21 ADG (kg/day)	1.69	1.85	1.50	2.29	2.00	2.03	0.147	<0.001	0.050	0.098
Mortality (pigs/litter)	1.15 (3.15)	0.10 (2.71)	1.30 (3.67)	0.81 (2.25)	0.88 (2.42)	0.94 (2.57)	0.200	0.013	0.31	0.66

3.2.2. Plasma Metabolites in Sows

Day 1

Sows fed the CON diet tended to have lower plasma BCAA concentrations compared to those fed SIMLUC 2 (0.52 vs. 0.64 nmol, respectively, $p = 0.088$) (Table 5). Plasma NEFA concentrations were lower in primiparous compared to multiparous sows (151 vs. 327 mM, respectively, $p < 0.001$) (Table 5). Sows fed the CON diet had higher plasma glucose concentrations overall (6.56 vs. 5.67 mM, respectively, $p = 0.03$) (Table 5). A trend for an interaction between parity and diet was observed such that sows fed SIMLUC 2 had lower glucose plasma concentrations compared to all other groups ($p = 0.088$) (Table 5). There were no other significant main or interactive effects observed (Table 5).

Table 5. Plasma metabolites of primiparous sows and multiparous sows fed either the control diet (CON) or SIMLUC 2 at D1 post-farrowing.

Parity (P)	Primiparous		Multiparous		SED	*p*-Value		
Diet (D)	CON	SIMLUC 2	CON	SIMLUC 2		P	D	P × D
BCAA + nmol	−0.61 (0.54)	−0.45 (0.64)	−0.69 (0.50)	−0.43 (0.65)	0.162	0.65	0.088	0.66
NEFA + µM	5.07 (159)	4.96 (143)	5.83 (340)	5.75 (314)	0.308	<0.001	0.64	0.96
Glucose mM	6.28	6.29	6.84	5.05	0.462	0.14	0.030	0.088
Urea mM	17.8	17.5	17.5	17.5	0.23	0.64	0.50	0.33
Total Protein pg/mL	630	631.5	610	641	33.1	0.87	0.57	0.53

+ Due to skewed data the values were Loge transformed before statistical analysis. Back transformed means are presented in parentheses.

Day 10

Sows fed CON and SIMLUC 2 PreF diets had lower concentrations of plasma BCAA compared to those fed SIMLUC 2 PreF + PostF (0.45 vs. 0.38 vs. 0.52 nmol, respectively, $p = 0.03$) (Table 6). Furthermore, sows fed CON or SIMLUC 2 PreF diets had lower plasma NEFA concentrations compared to sows fed SIMLUC 2 PreF + PostF (119 vs. 138 vs. 250 µM, respectively, $p = 0.017$) (Table 6). Sows fed CON or SIMLUC 2 PreF diets had higher plasma glucose concentrations compared to those fed SIMLUC 2 PreF + PostF (5.69 vs. 5.62 vs. 4.51 mM, respectively, $p < 0.001$). There were no other significant main or interactive effects observed (Table 6).

Table 6. Plasma metabolites of primiparous and multiparous sows on D10 fed either a control (CON) diet or SIMLUC 2 diet fed pre-farrowing (PreF) or fed both pre-farrowing and 10 days post-farrowing (PreF + PostF).

Parity (P)	Primiparous			Multiparous			SED	*p*-Value		
Diet (D)	CON	PreF	PreF + PostF	CON	PreF	PreF + PostF		P	D	P × D
BCAA nmol	0.44	0.43	0.52	0.46	0.33	0.52	0.063	0.67	0.030	0.44
NEFA + µM	4.85 (127)	4.94 (139)	5.47 (238)	4.72 (111)	4.91 (136)	5.57 (262)	0.363	0.82	0.017	0.90
Glucose mM	5.58	5.92	4.95	5.79	5.31	4.07	0.421	0.16	<0.001	0.16
Urea mM	18.0	17.9	17.9	18.1	18.2	17.5	0.262	0.76	0.21	0.11
Total Protein pg/mL	674	641	627	668	639	690	42.5	0.53	0.57	0.44

+ Due to skewed data the values were Log_e transformed before statistical analysis. Back transformed means are presented in parentheses.

3.2.3. Piglet Metabolites

Day 1

Piglets born to sows fed the CON diet had higher circulating glucose compared to those born to sows fed SIMLUC 2 (8.62 vs. 7.61 mM, respectively, $p = 0.017$). There were no other significant main or interactive effects observed (Table 7).

Table 7. Plasma metabolites of piglets on D1 born to sows fed either a control diet (CON) or the SIMLUC 2 diet.

Parity (P)	Primiparous		Multiparous		SED	*p*-Value		
Diet (D)	CON	SIMLUC 2	CON	SIMLUC 2		P	D	P × D
BCAA nmol	0.41	0.40	0.38	0.40	0.071	0.81	0.93	0.70
NEFA + µM	5.78	5.68	5.60	5.58	0.132	0.20	0.50	0.69
Glucose mM	8.83	7.20	8.42	8.02	0.566	0.22	0.017	0.14
Urea + mM	2.86	2.87	2.84	2.90	0.024	0.35	0.63	0.68
Total Protein pg/mL	395	380	425	396	29.7	0.24	0.31	0.75

+ Due to skewed data the values were Log_e transformed before statistical analysis. Back transformed means are presented in parentheses.

Day 10

The GP had higher plasma NEFA concentrations overall in comparison to SP (570 vs. 489 µM, respectively, $p = 0.028$). There were no other significant main or interactive effects observed (Table 8).

Table 8. Plasma metabolites of piglets on D10 born to sows fed either a control diet (CON) or SIMLUC 2 diet fed pre-farrowing (PreF) or fed both pre-farrowing and 10 days post-farrowing (PreF + PostF).

Parity (P)	Primiparous			Multiparous			SED	*p*-Value		
Diet (D)	CON	PreF	PreF + PostF	CON	PreF	PreF + PostF		P	D	P × D
BCAA nmol	0.29	0.31	0.27	0.35	0.28	0.32	0.052	0.68	0.77	0.29
NEFA µM	587	545	578	525	505	437	60.2	0.028	0.63	0.45
Glucose mM	9.36	9.55	8.86	9.36	9.16	9.50	0.451	0.91	0.58	0.24
Urea mM	17.7	18.1	17.8	17.6	18.2	18.5	0.410	0.19	0.23	0.34
Total Protein pg/mL	472	457	460	518	476	467	28.7	0.18	0.36	0.65

4. Discussion

The litters of primiparous sows are born and weaned lighter and exhibit poorer growth in the pre-weaning period compared to those of multiparous sows [3,11]. Results from the current study demonstrated that the litter weights of primiparous sows can be improved by supplementing late gestation diets with lucerne or feeding a diet such as SIMLUC. However, it seems that to increase litter weights, these diets should be offered during late gestation and ceased no later than 3 days after farrowing before the primiparous are switched to a standard lactation diet. Furthermore, the beneficial effects of these diets do not seem to extend to litters of multiparous sows to the same extent as primiparous sows.

Increasing the growth of litters of primiparous sows is challenging in part due to their poorer milk yield. Milk availability is the limiting factor for piglet growth, with milk yield being lower in primiparous sows due to underdeveloped mammary tissue [12], lower voluntary feed intake and prolonged catabolic states during lactation [13,14]. Therefore, investigating nutritional interventions to target these challenges is required to improve the performance of GP. Depending on the source of dietary fibre fed during gestation, beneficial effects on sow welfare and feed intake during lactation have been observed, with greater effects being reported in younger sows [5,15,16]. Increased feed intake will presumably support lactation and growth of the litter. Both the LUC and SIMLUC diets contained higher crude fibre concentrations and higher amounts of soluble fibre than the control diet, which may assist in explaining the improved primiparous litter weights at D21. According to Jørgensen et al. [17], soluble dietary fibre sources such as potato pulp and sugar beet pulp can improve satiation due to increased swelling and water binding capacity resulting in delayed gastric emptying. This can result in a greater gut capacity, which may stimulate feed intake during lactation. Increased gut capacity would likely be particularly beneficial for primiparous sows due to their smaller size compared to multiparous sows, and this may also be one of the reasons for their lower feed intake and milk yield [18]. In the current study, millrun and barley were both used in Experiments 1 and 2 to increase the crude fibre content. However, they are not as fermentable as potato and sugar beet pulp and, hence, may not swell as much in the gastrointestinal tract. Alternatively, they may have induced satiation via the ileal brake, and actions on glucagon-like peptide (GLP)-1 and (or) GLP-2 and/or peptide tyrosine tyrosine (PYY) in the lower bowel [19]. Low feed intake during lactation has been reported in primiparous sows [20–26] and feed intake is generally insufficient to meet their nutrient requirements during lactation. It was unfortunate that due to commercial constraints feed intake was not able to be measured in this study. However, the higher D21 litter weights found in response to the LUC and SIMLUC suggests improved feed intake in these primiparous sows.

Sows consuming the SIMLUC diets in both experiments consumed more BCAA with a greater ratio of BCAA to lysine compared to those consuming the control diets, and when fed prior to farrowing, this also improved litter ADG and weights and average piglet weight of primiparous sows. Inclusion of dietary BCAA in gestation can support mammary gland growth and development [27]. Mammary gland development of the primiparous sows increases immensely during the last third of gestation [28,29], and mammary uptake and utilisation of BCAA increased when circulating BCAA are available [30]. Isoleucine and leucine are involved in protein synthesis in the mammary gland [31], and valine supplementation has been reported to enhance milk fat synthesis [32] and increase lactose in colostrum [10] when supplemented during late gestation. Increased development of the mammary gland during gestation for the primiparous sow is imperative, with mammary gland size being an indicator of milk yield [33]. Taken together, the dietary inclusion of more BCAA is a promising nutritional intervention to support mammary development of the primiparous sow and therefore a possible way to improve milk composition and yields. It must also be noted that, along with increased BCAA prior to farrowing, primiparous sows consumed more energy when switched to the CON diet after farrowing. This may have also supported higher milk yields and contributed to the increased growth of GP.

Although the SIMLUC diets were able to improve D21 litter weights in both Experiments 1 and 2, it seems that the timing and duration of feeding SIMLUC is critical. Feeding SIMLUC 2 from D110 of gestation to farrowing, and feeding LUC and SIMLUC 1 to 3 days after farrowing, were able to improve litter weights at D21 overall. However, extending the duration of feeding SIMLUC 2 to 10 days after farrowing had a deleterious effect on D21 litter weights of both primiparous and multiparous sows. The fact that the CON diet had greater energy and lysine values in comparison to the SIMLUC 2 diet also cannot be disregarded, and indeed the greater ADG and D21 weights observed in piglets from sows fed the CON diet in Experiment 2 compared to sows fed the PreF + PostF diet may be attributed to this. It also suggests that the lower DE and lysine consumed may have been insufficient to support milk production in mid-lactation.

When energy intake is limited, sows will increase lipid mobilisation to support lactation. The higher plasma NEFA concentrations in both primiparous and sows fed the SIMLUC 2 diet PreF + PostF indicate a mobilisation of adipose tissue, as plasma NEFA concentrations and NEFA entry rate are closely related in pigs [34]. Furthermore, this may have been particularly detrimental for primiparous litters, with the lowest litter weights at D21 found from primiparous sows fed SIMLUC 2 PreF + PostF. With less lipid reserves to mobilise than multiparous sows and reduced energy intake, primiparous sows of the SIMLUC 2 PreF + PostF diet were unable to support the metabolic demands of lactation. Unfortunately, P2 backfat measurements were not taken in this study and, therefore, more work is required to support this theory. Although the LUC and SIMLUC diets were higher in BCAA, which have been shown to improve protein content in milk and increase piglet weight during lactation [9], the suspected negative effect of a greater fibre content on feed intake may have negated the beneficial effects of BCAA on piglet growth when fed till day 10 after farrowing.

Although feeding SIMLUC during late gestation (Experiment 2) and up to 3 days after farrowing (Experiment 1) was able to improve litter weights in primiparous sows at D21, this beneficial effect did not extend to multiparous litters. This was also evidenced by the faster growth of GP of sows fed SIMLUC 2 PreF compared to the other primiparous groups. This finding was not observed in SP; rather, the SP from the CON diet grew faster than those exposed to the SIMLUC 2 diet. This may be due to a variety of factors. Primiparous sows experience intense growth of mammary tissue during the last third of gestation in comparison to sows who are already developed [35]. The amount of BCAA consumed from the SIMLUC diets may have provided more nutritional support to primiparous sows to aid in the growth and development of mammary tissue and, therefore, satisfying their requirements for protein deposition. The beneficial effect of dietary fibre on the reduction of stereotypies in younger sows should also be considered [36]. Edwards et al. [8] reported that administering LUC as an enrichment was shown to reduce stereotypical behaviour in the 18 h period prior to farrowing and more interactions with their piglets during early lactation. Alternatively, the improvement seen in GP may be attributed to the increased gastrointestinal capacity and increased intestinal residence time of digesta in the mature heavier sow compared to the growing primiparous sow [37]. The retention time of the digesta in the gastrointestinal tract may have been longer in multiparous sows. This, in turn, may have suppressed their appetite for an increased period of time, resulting in reduced feed intake even after the SIMLUC 2 diet was stopped at D10. Unfortunately, feed intake was not measured in this study and therefore this is speculative and further work is required to support this.

Overall, SP outperformed GP during the pre-weaning period, as reflected in their heavier weights and faster growth, which agrees with numerous studies [3,11,38–41]. The poorer growth of GP has been attributed to a variety of factors such as reduced milk yield [21,42], reduced passive immunity in the perinatal period, and poor growth and development in the pre-weaning period [25]. Furthermore, GP have higher mortalities compared to SP in the first day of life and in the pre-weaning period overall. The neonatal period is marked by a high risk of mortality [43] due to crushing, starvation and hypothermia [44,45]. Furthermore, the low birth weight of GP puts them at a higher risk in this period due to low energy reserves [46]. Nutritional interventions targeted towards late gestation may mitigate the stressors associated with the neonatal period.

5. Conclusions

Taken together, these experiments demonstrate that feeding lucerne or diets such as SIMLUC in late gestation diets can improve GP growth performance. These diets contain higher levels of BCAA and fibre, which can improve mammary gland growth and support GP growth during the pre-weaning period. Furthermore, the SIMLUC 2 diet was more beneficial to GP in comparison to SP, which suggests that primiparous sows would benefit from targeted feeding strategies. However, feeding these diets until mid-lactation resulted in poorer growth performance of GP and SP. Therefore, feeding LUC or SIMLUC may be more successful in improving GP performance if fed only from late gestation to very early lactation, and then switched to a standard lactation diet.

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Institutional Review Board Statement: This study was conducted according to the guidelines of the Southern Australian Animal Welfare Act in accordance with the Australian Code for the Care and Use of Animals for Scientific Purposes, and approved by the Primary Industries and Regions South Australia (PIRSA) Animal Ethics Committee of the Government of South Australia (protocol code 09-19).

Data Availability Statement: Data available on request due to restrictions e.g., privacy or ethical. The data presented in this study are available on request from the corresponding author. The data are not publicly available due to commercial sensitivities.

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