Running head: nutritional strategies to reduce heat stress in sows

**Supplementation of selenium, vitamin E, chromium and betaine above recommended levels
improves lactating performance of sows over summer**

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Acknowledgements: The work was funded by Australian Department of Agriculture and Water Resources via the Carbon Farming Futures Program (194374-167) and Australian Pork Limited. Data collection was supported by Samantha Beer and Emily De Ruyter from R&I unit at Rivalea Australia. Fan Liu received International Postgraduate Research Scholarship and Australia Postgraduate Award from the Australian Commonwealth Government as well as a study award from Australian Pork Limited.

Abstract

Heat stress (HS) exacerbates the body weight loss of lactating sows and reduces litter weight gain. Selenium (Se), vitamin E (VE), chromium (Cr) and betaine have been shown to ameliorate symptoms of HS, and yeast nucleotides and mannan oligosaccharides have been reported to improve lactational performance and immune response in pigs. Therefore, a combination of these nutrients may improve lactational performance of sows in summer. The effects of two nutritionally enhanced diets on lactational performance of sows in summer were investigated in two experiments. In Experiment 1 we compared the effects of a nutritionally fortified diet (0.4 ppm Se, 100 IU/kg VE, 0.4 ppm Cr and 0.2% betaine; SVCB diet) with the NRC 2012 standard diet (0.15 ppm Se, 44 IU/kg VE) on lactational performance of sows in summer. Results showed the SVCB diet reduced body weight loss ($P = 0.039$) and tended to reduce backfat loss ($P = 0.075$) of sows without affecting feed intake, while litter weight gain was not influenced. In Experiment 2 we further enhanced the nutrients in the SVCB diet (0.8 ppm Se, 1% yeast nucleotides, and 0.1% mannan oligosaccharides; SMN diet). Results showed the SNM diet did not improve feed intake of sows, farrowing performance, or litter weight gain compared with the SVCB diet, but increased body weight loss of the third parity sows ($P = 0.037$). Overall, a combined supplementation of Se, VE, Cr, and betaine above the NRC recommended levels can reduce mobilization of body reserve of lactating sows in summer.

Introduction

Heat stress (HS) compromises the health and productive performance of pigs. Lactating sows are particularly susceptible to HS (Williams et al. 2013) due to the high metabolic heat production associated with milk production. Heat stress exacerbates body weight loss of lactating sows and reduces pre-weaning litter weight gain (Black et al. 1993). The decreased feed intake and the direct impacts of HS both contribute to compromised lactational performance. On the one hand, pigs reduce feed intake to minimize the thermic effect of feed and heat production for adapting to a hot environment (Huynh et al. 2005; Renaudeau et al. 2011). The reduced feed intake limits the total nutrients input and it is responsible for a significant portion of the impacts of HS (Pearce et al. 2013a; Pearce et al. 2013b). On the other hand, to prevent heat stroke the animals must place a premium on heat dissipation and survival over other biological processes. This results in a compromised physiological state that diverts energy from efficient production through increased maintenance cost. For example, as reported in pigs, the accelerated respiration for heat dissipation, increased synthesis of heat shock protein for preventing cellular damage (Pearce et al. 2012; Liu et al. 2016), inflammatory response (Ganesan et al. 2016), and the cost for repairing the damaged tissues (Liu et al. 2016) are all energy expensive, which can further increase the mobilization of sow body reserve and compromise the energy and nutrients supply for milk production. The thermal comfort zone for sows lies between 12 °C and 22 °C, whereas for piglets is between 30°C and 37°C (Black et al. 1993). The differences between the thermal comfort zones of sows and piglets means that managing periods of summer heat events via environmental engineering control alone is difficult, and indeed often not economically feasible. Nutritional strategies may provide a simple and cost-effective solution to mitigate HS, especially if used in conjunction with some engineering interventions.

However, the present Nutrient Requirements of Swine (National Research Council (NRC) 2012) are not formulated for environmental temperatures above 30 °C. Current nutritional strategies target the aetiology of its negative impacts (Cottrell et al. 2015) and may preserve energy for lactation requirement; thus, they may mitigate mobilization of body reserve of sows and improve pre-weaning piglet performance. Functional nutrients such as selenium (Se), vitamin E (VE), chromium (Cr), and betaine above the NRC recommendations have been shown to alleviate various impacts of HS in growing pigs in separate experiments. For example, Se and VE are two antioxidants synergistically counteracting oxidative stress and gut damage in heat-stressed pigs (Liu et al. 2016). Chromium is an insulin sensitizer,

and a supplementation of its bioavailable form, the Cr picolinate, improved average daily feed intake (ADFI) in the growing pigs in summer (Hung et al. 2014). Betaine supplementation could mitigate the increased intestinal permeability in heat-stressed pigs (Gabler et al. 2013) and decrease total heat production (Schrama et al. 2003). Given the respective potential of the above nutrients in reducing HS in pigs, it is of a practical importance to pig industry to understand whether a combined supplementation of those nutrients can improve the lactational performance of sows during summer. Therefore, the aim of the Experiment 1 of the current study was to investigate the effects of the combined supplementations of dietary Se (0.4 ppm), VE (95 IU/kg), Cr (0.4 ppm) and betaine (0.4%) above the NRC recommendation (0.15 ppm Se and 44 IU/kg VE) on the lactational performance of sows in summer. We hypothesize that the sows supplemented with a combination of these nutrients have superior lactational performance in summer, as measured by feed intake, change of body reserve and litter weight gain.

Experiment 2 was conducted to further improve the lactational performance of sows by fortifying the nutritional supplements used in the Experiment 1. Three additional functional nutrients which have proved beneficial to reducing HS or improving lactational performance under thermoneutral conditions were added in a combination. Firstly, a supranutritional amount of Se (0.8 ppm) was added to further enhance glutathione peroxidase activity to reduce HS-induced oxidative stress, because a similar level of Se (1.0 ppm) supplementation was shown to ameliorate the physiological response to HS in pigs (Liu et al. 2014). Secondly, yeast mannan oligosaccharides are immuno-modulators and improve immunity in disease challenged pigs (Che et al. 2012), and thus it may regulate the HS-induced inflammatory response (Ganesan et al. 2016). Thirdly, yeast nucleotides provide substrates for cell metabolism and enhance immunity of piglets (Hung et al. 2015), and thus may improve the health and growth performance of nursery pigs. Therefore, in the Experiment 2 we hypothesize that supplementing supranutritional Se, yeast mannan oligosaccharides and yeast nucleotides can further improve the lactational performance of sows in summer, compared with the nutritionally-enhanced diet used in Experiment 1.

Materials and Methods

Animals and experimental design

In Experiment 1, a total of 45 third parity and 30 fourth parity sows (PrimeGro™ Genetics, Corowa, NSW, Australia) were selected into experimental farrowing sheds located in the Research and Innovation unit at Rivalea Pty Ltd during a summer period of the southern hemisphere (January-February, 2016).

Within each parity group the sows were randomly allocated to either a diet formulated to NRC 2012 standard (NRC diet) or a nutritionally-enhanced diet (SVCB diet) upon entering the farrowing sheds at approximately 9 days (on average) before farrowing until weaning (average of 27 days post-farrowing). The NRC diet contained 14 MJ/kg DE, 0.15 ppm Se, 44 IU/kg VE. As Cr and betaine are not specified by NRC 2012, they were not included in the control diet. The SVCB diet was isoenergetic to NRC diet but fortified with selenized yeast (0.4 ppm), VE (95 IU/kg), Cr picolinate (0.4 ppm Cr) and betaine (2 g/kg) (**Table 1**). The experiment was conducted under commercial settings and each farrowing shed only had two feed lines. This meant that each experiment was limited to a single control and one experimental diet, as more combinations could not be accommodated.

In Experiment 2, a total of 102 second parity and 65 third parity sows (PrimeGro™ Genetics, Corowa, NSW, Australia) were selected into the same experimental farrowing sheds as the first experiment during summer (January-March, 2013). Within each parity group the sows were randomly allocated to either the SVCB diet or a further nutritionally-enhanced diet (SNM diet) upon entering the farrowing sheds at approximately 9 days before farrowing until weaning (average of 18 days post-farrowing). The SVCB diet used in Experiment 2 was formulated as per Experiment 1. The SNM diet was isoenergetic to SVCB diet with additions of 0.3% algae-based Se (Se 0.8 ppm, EconomasE®), 1% yeast nucleotide product (Nupro®), and 0.1% yeast mannan oligosaccharide (Actigen®) (**Table 1**). EconomasE®, Nupro® and Actigen® were all from Alltech Inc., Nicholasville, KY.

In both experiments, all sows were housed in individual farrowing cage without cooling equipment in the sheds. Each sow was fed 2.5 kg of diet per day before farrowing, and 3.5 kg of diet per day for the first three days after farrowing, then *ad libitum* from four days after farrowing until weaning. Feed refusals were recorded and removed at 07:30 h daily to estimate feed intake. During the *ad libitum* feeding phase the feeders were visually checked and topped-up with 3 kg of the diet at 11:30 h and 14:30 h when insufficient feed was noticed. Water was supplied *ad libitum* via nipple drinkers.

Environmental temperature and respiration rate

Temperature data from the both experiments were obtained from the website (<http://www.bom.gov.au>) of the Bureau of Meteorology, Australia. Observations were drawn from Corowa Airport (station ID: 074034), NSW, Australia, located 2 km from the experimental farrowing sheds. In Experiment 1,

respiration rate of individual pig was counted when the outside temperature exceeds 30°C. Respiration rate was not recorded in Experiment 2.

Evaluation of farrowing and lactation performance

Sow body weight and backfat thickness were recorded at entry into the farrowing shed and at weaning. Backfat thickness was measured via ultrasound (Pork Scan Pty. Ltd., Australia) at the P2 site (65 mm from the midline over the final rib). The number of total born alive, stillborn and mummified piglets were recorded and updated twice per day for sows that were farrowing. Within 48 h after farrowing, the surviving piglets were counted and weighed. To achieve a standardized litter size between dietary treatments, the piglets were fostered across dietary treatment groups, so that the subsequent lactation performance could be compared. Litter size and weights were measured at cross-fostering and at weaning.

Statistical analysis

The normality of distribution and the homogeneity of variance of the data was validated by Shapiro-Wilk test and Levene's test respectively, then the data were analysed by two-way ANOVA in GenStat 15th edition (VNS international, UK) for the main and interactive effects of sow parity and dietary treatments. Results were presented as mean $\pm$ average standard error of difference (SED). Residual standard deviation is calculated as the square root of the residual mean square.

Results

Experiment 1

In Experiment 1, the averaged minimum and maximum daily temperatures over the experiment were 16.1 $\pm$ 4.3 °C and 32.9 $\pm$ 3.8 °C (mean $\pm$ SD). The maximum temperature of all 64 experimental days were greater than the upper limit of the thermal neutral zone of sows (22°C) (**Fig. 1**).

Respiration rate was not affected by the sow parity ($P = 0.49$) or the dietary treatment ($P = 0.50$) (**Fig. 2**). Parity 3 sows consumed more feed than parity 4 sows (5.93 vs 5.54 kg for the ADFI of parity 3 and 4 sows, $P = 0.045$), but the ADFI was not affected by dietary treatment (**Table 2**). The body weight of sows at entry to the farrowing house was greater in higher parity sows (297 and 311 kg for parity 3 and 4 sows, $P = 0.019$), whereas the body weights were balanced between the dietary treatments ($P = 0.15$). At weaning, the body weights of sows became similar between parity 3 and 4 sows, and the body weight of sows was not affected by dietary treatment. While the body weight loss of sows was similar between

parities, however, the sows fed on the SVCB diet lost less body weight than those on the NRC diet (-42 vs -34 kg for NRC vs SVCB diet, $P = 0.039$). Backfat depth (P2) of sows were not significantly different between parities or dietary treatments at entry or at weaning. However, the reduction in P2 backfat between entering the farrowing shed and weaning tended to be reduced by the SVCB diet (-4.2 vs -2.2 mm for NRC and SVCB diet, $P = 0.075$). Cross-fostering the piglets standardized the litter size and litter weight between the parities and between the dietary treatments, and the litter size and litter weight remained similar between the parities and between the dietary treatments at weaning. The calculated litter weight gain was not affected by the sow parity or the dietary treatment (**Table 2**).

In Experiment 1, the number of piglets born alive tended to be greater in the parity 3 than the parity 4 sows (13.2 and 12.1 for parity 3 and 4 sows, $P = 0.090$). The number of mummified or still born piglets was not affected by parity. None of these farrowing parameters was influenced by dietary treatments (**Table 3**).

Experiment 2

In Experiment 2, the average minimum and maximum daily temperatures over the experiment were 15.8 ± 3.67 °C to 31.9 ± 5.00 °C (mean $\pm$ SD). The maximum temperature of all 47 experimental days were greater than the upper limit of the thermal neutral zone of sows (22°C) (**Fig. 3**).

In Experiment 2, the parity 2 and 3 sows consumed similar amount of feed, and the dietary treatment did not affect the feed intake (**Table 4**). The body weight of sows at entry to farrowing house was greater in higher parity sows (259 and 284 kg for parity 2 and 3 sows, $P < 0.001$), whereas the body weight was balanced between the dietary treatments. At weaning, body weight of sows remained greater in higher parity sows (224 and 250 kg for parity 2 and 3 sows, $P < 0.001$). The body weight of sows at entry and weaning were not affected by the dietary treatment. The losses of sow body weight were similar between parities ($P = 0.60$), while SNM diet increased the body weight loss (-31 and -34 kg for SVCB diet and SNM diet, $P = 0.037$). This was particularly so for the parity 3 sows, as evidenced by an interaction between parity and diet ($P = 0.040$). While backfat depth (P2) of sows was not different between parities at entry to the farrowing sheds, at weaning parity 2 sows had a less backfat depth than parity 3 sows (20.3 and 22.1 mm for the parity 2 and 3 sows, $P = 0.010$). The parity 2 sows lost more backfat depth than the parity 3 sows (-4.5 and -3.0 mm for parity 2 and 3 sows, $P = 0.007$) when calculating the change of backfat depth of sows between entry and weaning. Dietary treatment did not affect any measurements of

backfat depth. Litter size was standardized between parities after cross-fostering, however, the litter size became greater in parity 2 sows compared with parity 3 sows at weaning (9.9 and 9.4 for parity 2 and 3 sows, $P = 0.037$). The litter weight of the parity 2 sows was greater than the parity 3 sows post-fostering (18.2 and 16.8 kg for parity 2 and 3 sows, $P = 0.002$), but became similar at weaning. The calculated litter weight gain was not significantly different between the parity 2 and 3 sows. None of the litter measurements were influenced by the dietary treatment (**Table 4**).

In Experiment 2, the number of piglet born alive was greater in the parity 3 sows than the 2 sows (10.9 and 12.1 piglets for parity 2 and 3 sows, $P = 0.006$). Numbers of mummified and stillborn piglets were not affected by the parity of sows. The dietary treatment did not affect number of born alive, stillborn or mummified piglets (**Table 5**).

Discussion

The average minimum and maximum daily temperature in Experiment 1 (15.8 ± 3.67 °C to 31.9 ± 5.00 °C (mean $\pm$ SD)) and Experiment 2 (16.1 ± 4.3 °C to 32.9 ± 3.8 °C (mean $\pm$ SD)) were both above the thermal comfort zone (12-22 °C) of lactating sows. The normal respiration rate of sows under thermoneutral conditions could not be measured in the current studies, however, has been reported to be approximately 20- 30 breaths per min (Quiniou and Noblet 1999; Muns et al. 2016). By comparison, in Experiment 1 the respiration rate of sows averaged 54 breaths per min when the outside temperature was above 30°C. This nearly twofold increase in respiration rate demonstrates increased efforts by the sow to dissipate heat via respiratory route, and it is an indicator that they were experiencing HS. In Experiment 1 a combination of Se (0.4 ppm), VE (100 IU/kg), Cr (400 ppb) and betaine (2 g/kg) were supplemented versus a NRC control and showed improved resilience to HS, as indicated by reduced body weight and backfat loss independent of feed intake in the sows fed the SVCB diet. The Experiment 2 was conducted to investigate if a further fortification of the SVCB diet with supranutritional Se (0.8 ppm), mannan oligosaccharide (0.1%) and nucleotides (1%) can further enhance farrowing and lactating performance of sows in summer. The results from this study indicated SNM diet did not improve lactational performance of sows compared to the SVCB diet, as evidenced by an increased body weight loss in the parity 3 sows without improvements in ADFI or litter weight gain. Overall, a combined supplementation of Se, VE, Cr and betaine was beneficial in improving lactational performance of sows in summer but no further improvement was observed with the additional fortification.

The SVCB diet reduced the loss of body weight and backfat without compromising the litter weight gain, although ADFI was not improved. These findings suggest that the total energy expenditure of sows was reduced by SVCB diet and therefore fewer body reserve were mobilized to meet the total energy output. As lactating sows prioritize the energy expenditure towards milk production, the extra energy cost spared by the SVCB diet was presumably due to alleviations of HS. Selenium and VE are important dietary antioxidants, and a combined supplementation of Se and VE above the NRC recommended levels was able to reduce markers of oxidative stress in the heat-stressed pigs (Liu et al. 2016) and ruminants (Chauhan et al. 2014; Chauhan et al. 2016). Oxidative stress plays a role in tissue damages and metabolic disorders in animals (Celi and Gabai 2015), thus reducing oxidative stress has been shown to alleviate the increased intestinal permeability in heat-stressed pigs (Liu et al. 2016) and improve growth performance of sheep (Chauhan et al. 2016). Besides, Se may improve thermoregulatory ability of animals, for example, Se administration ameliorated the increase of rectal temperature in sheep (Alhidary et al. 2012) and lactating dairy cows (Shwartz et al. 2009) subjected to HS. Chromium improves insulin sensitivity (Amoikon et al. 1995) and growth performance (Sales and Jancik 2011) in pigs. Improving insulin sensitivity can facilitate the microcirculation of skin (Serné et al. 1999; Forst et al. 2006) thus facilitate the radiant heat dissipation, and Cr has been shown to facilitate vaso-relaxation (Abebe et al. 2010). Chromium supplementation increased feed intake and decreased blood cortisol concentration in growing-finishing pigs during summer (Hung et al. 2014), and Cr mitigated the increased rectal temperature and respiration to HS in growing pigs (Liu et al. 2015). Betaine can act as an osmolyte to protect cells in the stress condition and can also donate methyl component to provide substrates for protein synthesis (DiGiacomo et al. 2014). Betaine supplementation can decrease total heat production and maintenance requirement in pigs (Schrama et al. 2003), which could also help alleviate HS. Besides, betaine supplementation can protect against the effects of the HS damage on the intestine (Gabler et al. 2013). The combined supplementation of Se, VE, Cr and betaine separately or synergistically reduced comprehensive impacts of HS, and therefore sows spent less energy coping HS and thus mobilized fewer body reserves.

The SNM diet did not further improve farrowing and lactational performance compared with the SVCB diet. Surprisingly, SNM diet increased sows body weight loss over lactation during summer within the parity 3 sows. Moreover, the extra amount of mobilized body reserve in the parity 3 sows fed SNM diet did not contribute to the litter weight gain, suggesting the sows on this type of diet had greater energy

expenditure. We cannot identify the nutrient in the SNM diet which increased the body weight loss of sow, but supranutritional Se at the high dietary concentration is implicated, because a prolonged supranutritional Se supplementation (0.5-3.0 ppm, for 8 or 16 weeks) has been reported to have adverse impacts on insulin homeostasis in pigs housed under thermoneutral conditions (Liu et al. 2012; Pinto et al. 2012). The impacts maybe more severe in the high parity sows as they are more insulin resistant due to the plateau in maternal weight gain. Another possibility of the increased body weight loss was due to the mannan oligosaccharides, because supplementation with 0.2% with mannan oligosaccharides has been shown to increase the body weight loss of sows from 33 kg to 49 kg during lactation (Frank et al. 2006); however, the exact mechanism remains unknown. Despite the side effects, the positive effects of supplementation with mannan oligosaccharides were evidenced in terms of improving immunoglobulin concentrations in the milk of sows (Czech et al. 2010), piglet birth weight (Czech et al. 2010), and reduce the numbers of mummified piglets (Frank et al. 2006). Nucleotides supplementation increased nucleotide concentration in the milk, but did not affect sow body condition or nursing piglet performance (Plante and Farmer 2011). Similarly, replacing 1% soybean meal with nucleotides in the late gestating diet of sows did not affect litter size, litter growth or piglet mortality (Hung et al. 2015). Therefore, although mannan oligosaccharides and nucleotides are conditionally beneficial to lactational performance, they did not further improve lactational performance of the sows fed a diet contained optimized level of Se, VE, Cr and betaine.

In conclusion, a combination of Se, VE, Cr and betaine above the NRC recommended levels can reduce the loss of body reserve of lactating sows during HS and therefore are recommended to be included in a summer ration.

Conflict of interest

The authors confirm that they have no conflict of interest.

Ethical approval

The procedures that involved animals in current study were in accordance with Australian Code for the Care and Use of Animals for Scientific Purposes (8th edition, 2013) and approved by the Animal Ethics Committee of Rivalea Pty Ltd, Corowa, NSW, Australia.

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Tables

Table 1 Composition of experimental diets

Ingredients	% of fed basis		
	NRC diet	SVCB diet	SNM diet
Wheat	57	57	55.2
Barley	11.5	11.5	7
Flour offal	5.6	5.6	10.6
Canola meal, 35%	7.5	7.5	5
Tallow	6.6	6.6	6.6
Meat meal, 66%	5.1	5.1	6
Blood meal	0.7	0.7	0.9
Lupin kernels	0	0	5
Soybean meal, 48%	2	2	0
Betaine	0	0.2	0.2
Salt	0.35	0.35	0.35
Limestone	0.83	0.83	0.83
DL-methionine	0.1	0.1	0.1
Lysine	0.37	0.37	0.35
Threonine	0.16	0.16	0.15
Trace mineral premix ^a	1	1	1
Vitamin blend ^b	0.13	0.13	0.13
Selenized algae	0	0	0.03
Yeast nucleotides	0	0	1
Yeast mannan oligosaccharides	0	0	0.1
<i>Calculated nutrients composition</i>			
DE (MJ/kg)	14.9	14.9	14.9
Protein (%)	16.2	16.2	17.3
Fat (%)	8.6	8.6	8.8
Available phosphorus (%)	0.45	0.45	0.5
Calcium (%)	0.89	0.89	0.88
Lysine (%)	0.99	0.99	1.02
Selenium (mg/kg)	0.15	0.40	0.79
Vitamin E (IU/kg)	44	95	95
Chromium (mg/kg)	0	0.4	0.4

^a supplied per kg of diet: copper, 8.0 mg; manganese, 30 mg; zinc, 60 mg; iron, 80 mg; iodine, 2.0 mg; selenium and chromium concentrations varies in the three diets.

^b supplied per kg of diet: vitamin A, 15000 IU; vitamin D₃, 3250 IU; vitamin K, 1.0 mg; vitamin B-1, 1.5 mg; vitamin B-2, 5.0 mg; vitamin B-6, 3.0 mg; vitamin B-12, 135 µg; Niacin, 20 mg; pantothenic acid, 15 mg; folic acid, 20 mg; vitamin C, 100 mg; biotin, 200 µg; Vitamin E concentration varies in the three diets

Table 2 Lactating performance of sows in Experiment 1

Variables	Parity 3		Parity 4		SED	P-values			Residual Standard Deviation °
	NRC diet	SVCB diet	NRC diet	SVCB diet		Parity	Diet	Interaction	
	n=14	n=31	n=11	n=19					
ADFI (kg)	5.74	6.02	5.27	5.67	0.288	0.045	0.11	0.75	0.81
Body weight (kg)									
Entry	304	294	317	309	8.7	0.019	0.15	0.97	24.5
Wean	263	268	268	272	8.8	0.30	0.79	0.50	24.6
Change	-38	-32	-49	-37	5.9	0.074	0.039	0.54	16.1
P2 backfat depth (mm)									
Entry	28.0	27.0	30.5	28.2	1.83	0.18	0.24	0.61	4.97
Wean	25.0	25.2	25.5	25.4	1.82	0.94	0.78	0.92	4.93
Change	-3.6	-1.8	-4.5	-2.8	1.60	0.075	0.28	0.86	4.32
Litter size									
Cross-fostered	11.9	12.2	11.9	11.9	0.38	0.64	0.48	0.82	1.11
Wean	10.6	10.2	9.9	9.6	0.70	0.19	0.48	0.95	1.94
Litter weight (kg)									
Cross-fostered	18.3	17.8	17.9	18.0	0.92	0.99	0.68	0.70	2.64
Wean	85.5	86.2	78.0	80.0	6.52	0.15	0.94	0.77	18.4
Gain	67.2	68.4	60.1	62.1	6.49	0.15	0.89	0.81	18.1

^a NRC diet contains selenium (0.15 ppm), vitamin E (44 IU/kg), and does not contain chromium or betaine

^b SVCB diet contains selenium (0.4 ppm), vitamin E (95 IU/kg), chromium (0.4 ppm), betaine (2 g/kg)

^c Residual standard deviation was calculated as the square root of the residual mean square (degree of freedom =71 for all variables)

Table 3 Farrowing performance of sows in Experiment 1

Variables	Parity 3		Parity 4		SED	<i>P</i> -values			Residual Standard Deviation ^c
	NRC ^a diet	SVCB ^b diet	NRC diet	SVCB diet		Parity	Diet	Interaction	
	n=14	n=31	n=11	n=19					
Born Alive	13.2	13.2	13.0	11.6	0.98	0.090	0.41	0.35	2.65
Mummified	0.4	0.3	0.4	0.4	0.22	0.69	0.45	0.84	0.59
Stillborn	1.4	1.1	1.3	1.7	0.53	0.25	0.96	0.41	1.45

^a NRC diet contains selenium (0.15 ppm), vitamin E (44 IU/kg), and does not contain chromium or betaine

^b SVCB diet contains selenium (0.4 ppm), vitamin E (95 IU/kg), chromium (0.4 ppm), betaine (2 g/kg)

^c Residual standard deviation is calculated as the square root of the residual mean square (degree of freedom =71 for all variables)

Table 4 Lactating performance of sows in Experiment 2

Variables	Parity 2		Parity 3		SED	<i>P</i> -values			Residual Standard Deviation ^c
	SVCB ^a diet n=52	SNM ^b diet n=50	SVCB diet n=32	SNM diet n=33		Parity	Diet	Interaction	
ADFI (kg)	5.52	5.49	5.79	5.57	0.21 0	0.27	0.47	0.51	0.94
Body weight (kg)									
Entry	259	259	283	285	4.3	<0.001	0.96	0.89	19.3
Wean	225	224	254	246	4.3	<0.001	0.22	0.26	19.2
Change	-34	-35	-29	-39	3.7	0.31	0.037	0.040	16.5
P2 backfat depth (mm)									
Entry	24.8	24.7	24.1	26.2	1.03	0.57	0.30	0.12	4.59
Wean	20.5	20.0	21.8	22.3	1.00	0.010	0.91	0.50	4.44
Change	-4.3	-4.7	-2.3	-3.9	0.79	0.007	0.18	0.32	3.50
Litter size									
Cross-fostered	11.2	11.2	11.2	11.1	0.16	0.98	0.86	0.77	0.78
Wean	10.0	9.9	9.4	9.5	0.33	0.037	0.90	0.70	1.48
Litter weight (kg)									
Cross-fostered	18.5	17.8	16.6	17.0	0.61	0.002	0.450	0.22	2.73
Wean	79.0	76.0	77.1	74.3	3.27	0.43	0.21	0.97	14.57
Gain	60.5	58.2	60.5	57.4	3.01	0.83	0.21	0.85	13.41

^a SVCB diet contains selenium (0.4 ppm), vitamin E (95 IU/kg), chromium (0.4 ppm), betaine (2 g/kg)

^b SNM diet is the SVCB diet fortified with 0.3% algae-based selenium (selenium 0.8 ppm), 1% yeast nucleotides, and 0.1% yeast mannan oligosaccharides

^c Residual standard deviation is calculated as the square root of the residual mean square (degree of freedom =163 for all variables)

Table 5 Farrowing performance of sows in Experiment 2

Variables	Parity 2		Parity 3		SED	<i>P</i> -values			Residual Standard Deviation ^c
	SVCB ^a diet	SNM ^b diet	SVCB diet	SNM diet		Parity	Diet	Interaction	
	n=52	n=50	n=32	n=33					
Born Alive	10.8	11.0	12.5	11.6	0.62	0.006	0.69	0.29	2.79
Mummified	0.1	0.1	0.2	0.2	0.09	0.11	0.85	0.41	0.42
Stillborn	0.6	0.6	0.8	0.7	0.22	0.52	0.91	0.73	0.98

^a SVCB diet contains selenium (0.4 ppm), vitamin E (95 IU/kg), chromium (0.4 ppm), betaine (2 g/kg)

^b SNM diet is the SVCB diet fortified with 0.3% algae-based selenium (selenium 0.8 ppm), 1% yeast nucleotides, and 0.1% yeast mannan oligosaccharides

^c Residual standard deviation is calculated as the square root of the residual mean square (degree of freedom =163 for all variables)

Figure captions

Fig. 1 Temperature records during Experiment 1

The temperature data were collected from Corowa Airport (station ID: 074034), NSW, Australia, which is two km from lactating sheds

Fig. 2 Respiration rate of the sows in Experiment 1

Respiration rate were measured when the environment temperature (outside the farrowing sheds) exceeding 30 °C. SVCB diet contains selenium (0.4 ppm), vitamin E (95 IU/kg), chromium (0.4 ppm), betaine (2 g/kg). SNM diet is the SVCB diet fortified with 0.3% algae-based selenium (selenium 0.8 ppm), 1% yeast nucleotides, and 0.1% yeast mannan oligosaccharides

Fig. 3 Temperature records during Experiment 2

The temperature data were collected from Corowa Airport (station ID: 074034), NSW, Australia, which is two km from lactating sheds

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Title:

Supplementation of selenium, vitamin E, chromium and betaine above recommended levels improves lactating performance of sows over summer

Date:

2017-10-01

Citation:

Liu, F., Cottrell, J. J., Collins, C. L., Henman, D. J., O'Halloran, K. S. B. & Dunshea, F. R. (2017). Supplementation of selenium, vitamin E, chromium and betaine above recommended levels improves lactating performance of sows over summer. TROPICAL ANIMAL HEALTH AND PRODUCTION, 49 (7), pp.1461-1469. <https://doi.org/10.1007/s11250-017-1348-y>.

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