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Effect of 0.3% sorghum ergot (*Claviceps africana*) in sow diets on plasma prolactin, lactation and piglet growth: regulatory implications

J.S. Kopinski[1], B.J. Blaney[1] and J.A. Downing[2]

[1]Department of Primary Industries and Fisheries, LMB No 4, Moorooka, Qld. 4105, Australia; [2]Department of Animal Science, University of Sydney, Camden, NSW 2570, Australia; John.Kopinski@dpi.qld.gov.au

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Abstract

The safety of 0.3% sorghum ergot in a sow diet was evaluated, this being the currently regulated limit for stock food in Queensland. The alkaloid content (mg/kg) of the test diet was: dihydroergosine (DHES), 1.1; dihydroelymoclavine, 0.15; and festuclavine, 0.05. The test diet was fed to 16 sows from ~6 weeks prior to farrowing, until weaning of piglets 4 weeks post-farrowing. Compared to 16 sows fed a control diet, there were no significant effects on either onset of lactation, piglet mortality, or litter performance. There was a trend for ergot to reduce plasma prolactin concentrations at farrowing, particularly in first-litter sows, but this did not meet the test for significance and there were no corresponding trends for reduced performance. The results support shorter-term investigations showing that a diet with 0.3% sorghum ergot is tolerated by sows, when it contains 1 mg DHES/kg or less. Data are presented indicating a significant correlation between % ergot and DHES in 26 different sources of infected sorghum. However, while a sample containing 0.3% ergot is most likely to contain 1 mg DHES/kg or less, this can range from <0.1 up to 5 mg DHES/kg, depending on maturity of ergot sclerotia present in infected grain. Consequently, the risk that occasional batches of grain with 0.3% ergot can contain up to 5 mg DHES/kg must be taken into account, and regulations should probably be revised, either to reduce ergot concentrations to 0.1%, or to incorporate maximum alkaloid (DHES) concentrations of 1 mg/kg, for sow feeds.

Keywords: regulation, standard, milk, alkaloid

1. Introduction

Sorghum ergot (*Claviceps africana*) was first detected in Australia in 1996 (Ryley *et al.*, 1996) and shortly thereafter, a limit of 0.3% in grain for stock food was regulated in Queensland (Anonymous, 2003). This decision took into account the lack of evidence of toxicity of sorghum ergot to livestock at that time compared to other ergot species such as rye ergot (*C. purpurea*), which collectively were limited in those regulations to 0.02% 'ergot'. However, the need to review the 0.3% limit became apparent when cases of toxicity in pigs and dairy cattle fed sorghum ergot were detected soon afterwards (Blaney *et al.*, 2000b).

The primary alkaloid which is produced by *C. africana* is dihydroergosine (DHES), with smaller amounts of festuclavine and dihydroelymoclavine (Frederickson *et al.*, 1991). Sorghum ergot alkaloids, in common with rye ergot alkaloids, reduce plasma prolactin (Blaney *et al.*, 2000a) and impair lactation of sows (Kopinski *et al.*, 2007a; 2008). Prolactin is essential in preparing the mammary glands to produce milk shortly after farrowing (Cowie *et al.*, 1980). There is usually a major surge in prolactin levels immediately before farrowing in the sow (Taverne *et al.*, 1979; Vale and Wagner, 1981), but we have shown that sows fed 1.5% sorghum ergot (7 mg alkaloid/kg, including 6 mg DHES/kg) for several days before farrowing do not demonstrate this surge, and milk production is completely

inhibited (Kopinski *et al.*, 2007a). Alkaloid concentrations of 4.2 and 5.6 mg/kg also impaired milk production. A level of 2.8 mg/kg (0.6% ergot) affected lactation of only one of nine pigs, a first-litter gilt which was completely agalactic, and it was concluded that the lower prolactin concentrations in gilts made them more susceptible to ergot. Once lactation has begun, prolactin is less critical as other mechanisms (e.g. sucking) help maintain the milk flow, but diets containing 3% sorghum ergot (16 mg total alkaloid/kg) can still affect prolactin and milk supply of sows in full lactation (Kopinski *et al.*, 2008). However, these experiments were conducted over relatively short periods. In the first experiment, ergot was fed for 6-10 days prior to farrowing, but withdrawn at farrowing (Kopinski *et al.*, 2007a) and in the second experiment, ergot was first fed at 14 days after farrowing and continued until weaning ~14 days later (Kopinski *et al.*, 2008). Consequently, they did not fully resolve the safety of the regulated limit of 0.3% sorghum ergot for continuous feeding over the pre-farrowing to weaning period.

From a regulatory standpoint there is a problem with the common practice of regulating ergot levels in feed using weight percentage. Earlier studies have shown that concentrations of DHES in individual ergot bodies separated from grain can vary over a wide range (from <0.01-0.7%), depending on maturity (Blaney *et al.*, 2003), especially since alkaloid production is mostly confined to mature sclerotial tissue (Mantle, 1973; Blaney *et al.*, 2006). Bulk grain which has been infected typically contains material recognised as 'ergot' which is predominantly sphacelial tissues with glumes attached, often overgrown with saprophytic *Cerebella* spp. (Blaney *et al.*, 2003). For this reason, examination of samples of naturally-infected bulk sorghum grain in Queensland has shown only a moderate correlation between 'ergot' and DHES concentrations: data are presented here to show that batches of bulk sorghum grain with 0.3% 'ergot' most frequently contain about 1 mg DHES/kg, but can range from <0.1 up to 5 mg/kg.

The objective of the present experiment was to provide a base line for the safety of prolonged feeding of sow diets containing the regulated limit of 0.3% sorghum ergot (1.3 mg alkaloids/kg), when fed from about six weeks prior to sows farrowing until weaning of piglets at four weeks of age. The experiment was not originally designed to compare the performance of gilts (primiparous sows) with multiparous sows, but the data were examined separately for these groups.

2. Materials and methods

Ergot and alkaloid concentrations in different batches of infected sorghum

Ergot and alkaloid concentrations were obtained in 26 samples of different infected sorghum batches submitted to this laboratory over several years to test for stock feed suitability (usually 1-2 kg). In each case, a representative sample of 200 g was set aside for physical inspection and separation and the remainder was milled through a 1 mm screen. All material recognised as 'ergot' (sclerotia, sphacelial tissues, overgrown moulds and attached floral parts) was physically separated and weighed. The milled grain samples were assayed for DHES and related alkaloids by a high-performance liquid chromatographic method (Blaney *et al.*, 2003).

Diet preparation

A pelleted sow diet was prepared which incorporated one batch of sorghum grain naturally infected with sorghum ergot. The composition of this diet was given by Kopinski *et al.* (2007a). It was then mixed at a specific proportion (1:10) with a control diet of identical composition but without ergot in order to achieve the target 0.3% ergot concentration. The alkaloid content of the 0.3% diet, assayed for alkaloids as in Blaney *et al*. (2003), was 1.3 mg/kg (dihydroergosine, 1.1 mg/kg; dihydroelymoclavine, 0.15 mg/kg; and festuclavine, 0.05 mg/kg).

Pigs, housing, feeding and experimental design

Thirty-two pregnant sows randomly selected from an 80-sow continuously-farrowing research piggery were utilised in this trial. Animals were inducted into the trial in groups of 4-6 each week as they reached about 6 weeks prior to their anticipated farrowing date. They were housed in individual farrowing crates, four to a farrowing room with window shutters to control ventilation. Temperature was maintained between 24-36 °C in January-February and 21-34 °C in March. Within each induction group, sows were randomly allocated to either the ergot treatment or a control diet. Overall sow management was maintained as per normal routine for this piggery.

Diets were restrictively fed twice each day following moistening (routine practice for this piggery), for periods that varied from 40-53 days prior to actual farrowing. Diets were held in separate bins for each sow so that actual intakes could be weighed weekly, while a scoop providing about 1 kg for gilts and 1.2 kg for sows was offered at each feeding. Residues were minimised and recorded. Following farrowing, the same dietary treatment allocations were maintained, but each sow was supplied increasing amounts of diet until eating to appetite. Water was provided *ad*

libitum via nipple drinkers in each crate. Weighed amounts of creep feed were offered to piglets in feeders protected from the sow, and consumption was recorded weekly after correcting for spillage and residues.

Any abnormal sow behaviour (e.g. feed refusals, ill health or diarrhoea) at feeding time was recorded by farm staff. Similar observations on unusual behaviour were conducted, where possible, around farrowing of each sow. In addition, on the day prior to farrowing, the swelling of udders and any colostrum leakage from each sow was noted. After farrowing, udder distension was rated by visual inspection and gentle palpation. Following farrowing of each sow, litter performance (number born alive, stillbirths, mummified foetuses and pre-weaning mortalities) and piglet weight at birth, at 10 days and at weaning were recorded. Due to the death of one sow soon after farrowing, which was not treatment-related, in the control sow group post-farrowing parameters are based on 9 animals. In line with normal practice on this piggery, a few piglets were fostered onto different sows to equalise litter sizes.

Blood collection and prolactin determination

Blood (10 ml) was sampled from the jugular vein of each sow upon induction into the trial (40-53 days prior to farrowing), and again at farrowing and at weaning. Samples were kept on ice until centrifuged and the separated plasma deep frozen until analysis of prolactin could be conducted on a single batch. Prolactin was determined by radioimmunoassay, as described previously (Blaney *et al.*, 2000a).

Animal ethics approval

This research was conducted with adherence to the 'Australian code of practice for the care and use of animals for scientific purposes' (NHMRC, 1997) and the 'Model code of practice for the welfare of animals, pigs' (SCARM, 1998). Animal ethics approval from The University Animal Ethics Committee (The University of Queensland) for the conduct of the study was granted prior to commencement of the work (Approval No SVSAP/069/DPI/PRDC).

Statistical analysis

Analysis of variance (ANOVA) was used to compare treatments (GenStats, 2006). The ANOVA model used was for a completely randomised design and error was estimated from sow to sow variation. The prolactin data were transformed ($\log_e$ x) prior to analysis of variance to correct for the positive skewness, and to stabilise the variance. Means were compared via the protected LSD procedure operating at the 5% level of significance. This experiment was not originally designed to compare the ergot tolerance of primiparous with multiparous sows, but the experimental data were treated separately after parallel investigations had suggested that gilts might be more susceptible to ergot (Kopinski *et al.*, 2007a).

3. Results

Relationship between ergot and alkaloid content

The relationship between 'ergot' as measured by physical separation and weighing, and alkaloid concentrations in 26 samples of infected sorghum is shown in Figure 1. This relationship is significant (P<0.01), and explains 27.0% of the total variation.

Lactation

All sows farrowed normally and every sow produced milk. This assessment was made from visual examination and palpation of udders, and sucking behaviour of the litters. No piglets required supplementary feeding with natural or artificial colostrum supplements.

Sow weight changes

Sow feed intake and live weight changes, for both the feeding period prior to farrowing and the lactation period, are given in Table 1. In this (and following) tables, the parity by treatment interaction means are uniformly reported. This approach was adopted because Kopinski *et al.* (2007a) indicated a differential treatment response by parities, and in the ANOVAs the interaction was significant (P<0.05) in 3 out of 25 analyses, which is a rate higher than expected from random chance.

Feed intakes showed differences from week to week but none were significant and did not appear to be related to

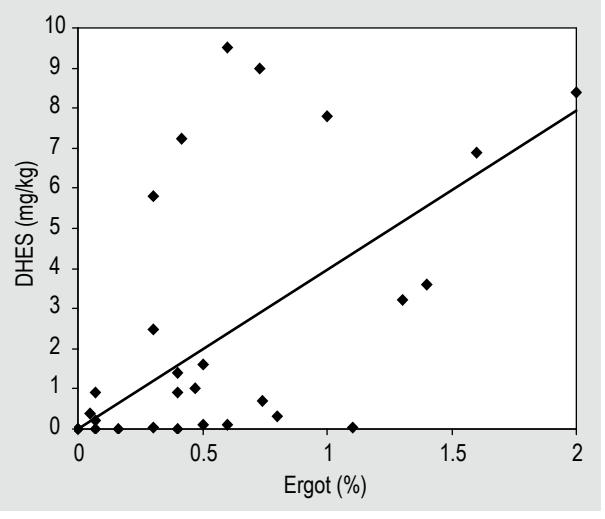

Figure 1. The relationship between sorghum ergot and DHES concentrations in batches of infected sorghum.

Table 1. Feed intake and live weight changes in gilts and multiparous sows fed 0.3% ergot or a control diet from prior to farrowing until weaning.

Treatment	Sows (n)	Mean parity	Pre-farrow feed intake (kg/d)	Post-farrow feed intake (kg/d)					Live weight (kg)			Live weight changes (kg)		
				Wk1	Wk2	Wk3	Wk4	Wk1-4 mean	Start	Farrow	End	Start to farrow	Farrow to weaning	Start to weaning
Control gilt	6	1	2.16	2.69	4.27	4.60	4.73	4.23	160^{x}	187	164^{x}	29.4	-22.4	4.13
Control sow	10	4	2.42	3.83	4.79^{b}	5.31^{b}	4.86^{b}	4.68^{b}	239^{z}	256	232^{z,b}	20.6	-24.2^{b}	-6.44^{b}
Ergot gilt	4	1	2.16	3.40	3.83	4.35	4.67	4.15	156^{x}	181	157^{x}	27.8	-20.7	0.75
Ergot sow	12	3.33	2.40	3.55	4.90	4.95	4.78	4.59	215^{y}	238	206^{y}	19.4	-32.3	-13.95
LSD (P=0.05)[a]			0.146	0.830	0.816	0.626	0.757	0.484	24.6	24.7	21.0	10.4	15.8	14.2

[a] LSD testing between means (in columns) is indicated by different letters (^{x,y,z}) only if the treatment effect, or treatment by parity interaction was significant (P<0.05).

[b] Values based on 9 sows, due to one death which was not treatment related.

ergot treatment. Gilts consumed less than multiparous sows both pre-farrowing and during the lactation periods, which is a typical feed intake pattern. Live weights reflected the typical difference between multiparous sows (>200 kg) and gilts (<180 kg) producing their first litter. All treatment groups gained weight (19-29 kg) prior to farrowing, and during lactation all lost weight, which is the normal pattern when fat stores are utilised for milk production. Gilts lost less weight than multiparous sows overall. Multiparous sows fed ergot lost more weight than control sows, although not significantly more. Gilts fed ergot lost less weight than control gilts overall, but not significantly less. There were no significant differences in overall sow weight change from start to weaning, from start to farrowing or from farrowing to weaning, although this may be due to the high level of variation in sow weights.

Litter performance

Litter performance data are given in Table 2. As is the norm, the average litter size of gilts was less than that of multiparous sows. A number of piglets were also fostered onto other sows within 48 hr of birth to roughly equalise litters during lactation, a standard commercial practice (compare Tables 2 and 4). There was no significant difference in birth weights, average daily gain and total litter gain between the control and the 0.3% ergot treatment groups overall. Piglets from gilts fed ergot were significantly heavier at day 10 than those from control gilts, and at weaning were significantly heavier than other groups, but this appeared to be a reflection of the higher initial piglet birth weights, fewer piglets in the litters on trial and the longer lactation period for this treatment group rather than

Table 2. Litter performance of gilts and sows fed 0.3% ergot or a control diet from prior to farrowing until weaning.

Treatment	Sows (n)	Piglets per sow[a]	Lactation period (days)	Piglet weight (kg)				Piglet gain (kg/d)	Litter gain (kg/d)	Total litter gain (kg)	Total creep intake (kg/litter)
				Birth	Birth on trial[b]	Aged 10 days	Weaned				
Control gilt	6	9.33	25.4^{x}	1.45	1.45	3.89^{x}	6.16^{x}	0.19^{x}	1.87	47.1	0.72
Control sow	9[d]	8.89	24.8^{x}	1.65	1.68	4.73^{y}	7.19^{y}	0.22^{x,y}	1.99	48.8	0.62
Ergot gilt	4	7.75	31.3^{y}	1.47	1.50	4.72^{y}	9.16^{z}	0.24^{y}	1.88	58.8	0.58
Ergot sow	12	9.58	27.5^{x,y}	1.49	1.53	4.47^{x,y}	7.43^{y}	0.22^{x,y}	2.04	55.8	1.35
LSD (P=0.05)[c]			4.32	0.214	0.221	0.740	0.966	0.033	0.539	15.2	0.877

[a] Mean number of piglets in each litter on trial for entire lactation period, after initial fostering and pre-weaning mortalities.

[b] Mean birth weight of those piglets on trial for entire lactation period, after initial fostering and pre-weaning mortalities.

[c] LSD testing between means (in columns) is indicated by different letters (^{x,y,z}) when the treatment effect, or treatment by parity interaction was significant (P<0.05).

[d] Due to the death of one sow after farrowing (unrelated to treatment) litter performance values are for 9 sows.

any ergot effect. This interpretation is supported by the similar daily gain both of individual piglets and of litters. There was no significant difference, probably due to the high variation, in litter creep feed consumption between any treatment groups.

Prolactin

Plasma prolactin concentrations are shown in Table 3. There were no significant differences between sows or gilts at ~43 days prior to farrowing; with the levels ranging from 0.8 to 6.0 µg/l. Prolactin levels at farrowing were much higher than ~43 days prior to farrowing. There was no significant effect of ergot treatment between control and ergot-fed sows. Prolactin in multiparous control sows ranged from 25 to 71 µg/l and from 11 to 80 µg/l in ergot-fed sows. However, the trend for lower levels found in gilts fed ergot (23 µg/l; range 15 to 38) compared to control gilts (41 µg/l; range 25 to 71) almost reached significance (P=0.08). At weaning, prolactin levels had declined to range from 1.1 to 36 µg/l, but again there were no significant differences between groups.

Reproductive performance

Reproductive performance of sows and gilts is compared in Table 4. There were no differences between the control and 0.3% ergot sows for litter size, nor were there any apparent treatment effects on number of mummified, stillbirths and pre-weaning mortalities. The normally expected differences between gilts and sows were observed, with gilts having significantly (P=0.05, LSD=2.30) smaller litters (~9.8 piglets) than older sows (~12.5 piglets), but this was independent of ergot treatment.

Table 3. Plasma prolactin in sows and gilts fed 0.3% ergot or a control diet measured at the start of treatment, at farrowing and at weaning.

Treatment	n	Prolactin concentration (µg/l)					
		Initially 40-53 days before farrowing		Farrowing within 2 days of farrowing		Weaning 26-28 days after farrowing	
		Mean[a]	Transform mean[b]	Mean	Transform mean	Mean	Transform mean
Control gilts	6	1.63	0.49	40.5	3.70	6.82	1.92
Control sows	10	1.98	0.68	49.0	3.89	7.92[d]	2.07
Ergot gilts	4	1.68	0.52	23.2	3.14	6.87	1.93
Ergot sows	12	1.74	0.55	41.4	3.72	8.07	2.09
LSD (P=0.05)[c]			0.681		0.583		1.122

[a] Back-transformed (geometric) mean.
[b] Transformed by $\log_e x$.
[c] LSD testing between transformed means (columns) showed no significant differences (P<0.05).
[d] Values based on 9 sows, due to one death which was not treatment related.

Table 4. Reproductive performance of gilts and sows fed 0.3% ergot or a control diet from prior to farrowing until weaning.

Treatment	Sows (n)	Average parity	Mean number of piglets/sow							
			Total born	Mummified	Still-born	Born alive	Foster on[1]	Foster off[2]	PWM[3]	Piglets on trial
Control gilt	6	1	9.83	0.17	0.33	9.33	1.17	0.5	0.67	9.33
Control sow	10	4	12.5	1.00	1.30	10.2	0.44	1.33	1.33	7.98
Ergot gilt	4	1	9.75	0.75	1.00	8.0	1.25	0.5	1.00	7.75
Ergot sow	12	3.3	12.5	0.67	0.42	11.41	0	1	0.83	9.58

[1] Piglets transferred onto these sows after farrowing to equalise litters.
[2] Piglets transferred off these sows after farrowing to equalise litters.
[3] PWM = pre-weaning mortality (deaths between birth to weaning, including fostered piglets).

Reproductive performance of gilts and multiparous sows combined is given in Table 5, and compared with the reproductive performance of those sows retained for a subsequent breeding cycle. There were no significant differences in mean number of piglets born alive, number of stillbirths and mummified foetuses, nor in days suckled and farrowing interval for sows in this parity and the subsequent parity.

4. Discussion

Milk production and litter performance

In this study all sixteen sows, including four gilts, when fed 0.3% ergot (1.3 mg alkaloid/kg) appeared to have a normal onset of lactation after farrowing. This normal lactation can be compared with the problems in lactation observed in one of three gilts fed 0.3% ergot (1.4 mg alkaloid/kg), one of two gilts fed 0.6% ergot (2.8 mg alkaloid/kg), and two of two gilts fed 0.9% ergot (4.2 mg alkaloid /kg) prior to farrowing (Kopinski *et al.*, 2007a). In that experiment ergot feeding ceased at farrowing, but in the current trial it continued until weaning.

Daily litter gains were also reduced in two primiparous sows that had previously been fed 0.9% ergot for 6 days prior to farrowing (Kopinski *et al.*, 2007a) and in one of two primiparous sows fed 3% ergot during mid-lactation (Kopinski *et al.*, 2008). In the current study with 0.3% ergot, there were no significant differences between treatments in either weight loss of sows during lactation, nor in daily litter weight gains, which we have previously shown to be affected by feeding 3% ergot (16 mg alkaloid/kg) during mid-lactation, indicative of reduced milk supply (Lewis *et al.*, 1978).

Average initial birth weight of piglets did not vary significantly between ergot and control sows and would not have been expected unless there was either a toxic effect, or a dramatic reduction in sow feed intake, as a result of ergot feeding. This observation differs from (Anderson and Werdin, 1977) who referred to a report of chronic (rye) ergotism resulting in sows having smaller piglets at birth, but as the actual time period of ergot feeding and the alkaloid type or amount fed were not stated, detailed comparisons cannot be made.

The young piglet, particularly until 14 days of age, is entirely dependent on nutrition from sow's milk and after this period the supply of creep feed can become important as a supplementary source of nutrition (Campbell, 1990). We observed that at 10 d of age the average weight of piglets was not different between litters of control and ergot-fed sows, indicating no problem in milk supply. This was further supported by the fact that there was no significant increase in creep consumption which we had previously observed with a much higher level of sorghum ergot (3.0%) fed during late lactation (Kopinski *et al.*, 2008).

Prolactin

The plasma prolactin changes that we observed in this study follow the usual pattern of a sharp increase around farrowing and a gradual decline to weaning (Vale and Wagner, 1981; Dusza and Krymowska, 1981; Schams *et al.,* 1994). In our previous study (Kopinski *et al.*, 2007a), prolactin values around farrowing in control multiparous sows averaged about 50 µg/l, although some sows ranged up to 400 µg/l. We also concluded that the lower prolactin production capability of gilts might make them more susceptible to ergot than multiparous sows. The lower

Table 5. Reproductive performance of all sows fed 0.3% ergot versus control diet, both in the current trial and in the next parity.

Treatment group	Period	Sows (n)	Mean number piglets			Days suckled	Farrowing Interval (days)
			Born alive	Mummified	Still-born		
Control[d]	trial [a]	16	9.9	0.7	1.0	25	146
Ergot[d]	trial [a]	16	10.5	0.7	0.6	28	146
LSD (P=0.05)[e]			1.87	0.7	1.13	3.73	1.97
Control	next [b]	12[c]	10.5	0.5	1.8	25	148
Ergot	next [b]	13 [c]	11.7	0.4	1.3	26	148
LSD (P=0.05)[e]			2.57	0.5	1.49	3.18	4.96

[a] Result for current parity (fed control or ergot diet).
[b] Result for subsequent parity (fed normal commercial diet).
[c] Some sows were culled from the piggery before this parity.
[d] Gilts and sows combined.
[e] LSD testing between means (in columns) did not show significant differences (P<0.05).

prolactin of ergot-fed gilts compared to control gilts in the current experiment tends to support this idea. Although no significant effects of this on milk production were observed, 0.3% ergot (1.3 mg alkaloids/kg) might be approaching the tolerance of gilts.

Reproductive performance of sows

In a previous trial (Kopinski *et al.*, 2007a), there appeared to be a slight tendency for mummified foetuses and stillbirths to increase in sows fed higher ergot concentrations. We ascribed this to litter size rather than an ergot effect, since stillbirths did not increase in sows given high doses of bromocriptine (Taverne *et al.*, 1982). No increase in mummified foetuses and stillbirths was observed in the present trial. In the previous trial, we also observed the subsequent mean farrowing interval to be extended by about 26 days, compared with controls, in 6 sows previously fed either 5.6 or 7 mg alkaloid/kg. However, no such effects were observed in the current experiment.

5. Conclusions and regulatory implications

No adverse performance effects were observed in sows fed 0.3% ergot (1.3 mg alkaloid/kg) for a period from ~6 weeks prior to farrowing until weaning at 4 weeks after farrowing. However, the trend towards reduced plasma prolactin concentration in the ergot-fed gilts suggests that this concentration of ergot may be close to the dietary level that can be tolerated. The data presented in Figure 1 indicate that occasional batches of sorghum grain with 0.3% 'ergot' can contain up to 5 mg alkaloids/kg, and this must be taken into account in the risk assessment. While % ergot remains a very useful screening procedure for bulk grain, it appears far less satisfactory as a tool for regulatory purposes. It appears that future revisions of the regulations should consider either reducing the maximum ergot concentration for sow diets to 0.1%, or else incorporating maximum permitted alkaloid (DHES) concentrations of 1 mg/kg for sow feeds. In addition to chromatographic procedures (Blaney *et al.*, 2003), an ELISA has been developed and validated (Molloy *et al.*, 2003) for such testing. However, over the past 10 years since it was first detected in Australia, significant ergot contamination of sorghum has fortunately been limited to a relatively few late-planted crops where cool, wet weather reduces pollen production and favours ergot infection (Ryley *et al.*, 2002).

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