JOURNAL OF ANIMAL SCIENCE
The Premier Journal and Leading Source of New Knowledge and Perspective in Animal Science

Effects of supplemental biotin during gestation and lactation on reproductive performance of sows: a cooperative study.

A J Lewis, G L Cromwell and J E Pettigrew

J ANIM SCI 1991, 69:207-214.

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://www.journalofanimalscience.org/content/69/1/207

American Society of Animal Science

www.asas.org

Downloaded from www.journalofanimalscience.org by guest on August 24, 2012

EFFECTS OF SUPPLEMENTAL BIOTIN DURING GESTATION AND LACTATION ON REPRODUCTIVE PERFORMANCE OF SOWS: A COOPERATIVE STUDY[1,2,3]

A. J. Lewis[4], G. L. Cromwell[5] and J. E. Pettigrew[6]

NCR-42 Committee on Swine Nutrition[7], University of Nebraska, Lincoln 68583-0908

ABSTRACT

A cooperative experiment to evaluate biotin addition to sow diets was conducted at three research stations using 303 litters. Primiparous and multiparous sows (overall average parity 2.8) were fed a 14% CP corn-soybean meal diet (140 μg/kg biotin), with or without supplemental biotin (330 μg added biotin per kg feed), throughout gestation and lactation. As many sows as possible were fed their respective diets through three successive parities. During gestation, sows were given from 1.82 to 2.27 kg of feed per day, depending on environmental conditions; during lactation sows had ad libitum access to feed. Supplemental biotin had no effect ($P > .35$) on sow weights at breeding, at d 109 of gestation, at farrowing or at weaning. No differences were found in litter size at birth ($P > .18$), but at d 21 of lactation, sows fed the diet containing supplemental biotin had larger litters than sows fed the unsupplemented diet (9.4 vs 8.7 pigs, respectively; $P = .01$). Pig weights at birth and d 21 of lactation were not affected ($P > .20$) by dietary treatment. Biotin supplementation did not affect ($P > .28$) the length of the interval from weaning to estrus. No evidence was found that feet cracks or bruises were reduced by biotin supplementation. The results indicate that biotin supplementation of a corn-soybean meal diet during gestation and lactation increased the number of pigs at d 21 of lactation, but it did not decrease the incidence of foot lesions.

Key Words: Sow Reproduction, Biotin, Feet, Wounds

J. Anim. Sci. 1991. 69:207–214

Introduction

The need for supplemental biotin in the diets of sows during gestation and lactation remains controversial despite numerous experiments. In a recent review of biotin in swine production, Kornegay (1986) stated that "Under some conditions supplemental biotin will improve litter size, conception rate, weaning to estrus interval, foot lesions and haircoat condition of swine; however, many questions concerning the availability, requirement and role of biotin remain unanswered." The NRC

[1]Journal Series No. 9104, Agric. Res. Div., Univ. of Nebraska.

[2]The assistance of D. A. Burosh (Univ. of Nebraska), J. H. Randolph (Univ. of Kentucky) and J. W. Rust (Univ. of Minnesota) is gratefully acknowledged.

[3]The biotin used in this research was donated by Hoffmann-La Roche, Inc., Nutley, NJ 07110.

[4]Dept. of Anim Sci., Univ. of Nebraska, Lincoln 68583-0908. To whom reprint requests should be addressed.

[5]Dept. of Anim. Sci., Univ. of Kentucky, Lexington 40546-0215.

[6]Dept. of Anim. Sci., Univ. of Minnesota, St. Paul 55108.

[7]The Committee during the course of this study included: G. L. Allee and J. L. Nelssen, KS; C. C. Calvert, ARS; T. R. Cline, IN; J. D. Crenshaw, ND; T. D. Crenshaw, WI; G. L. Cromwell, KY; R. A. Easter, IL; R. C. Ewan, IA; C. R. Hamilton and R. C. Wahlstrom, SD; A. J. Lewis, NE; D. C. Mahan, OH; E. R. Miller, MI; J. E. Pettigrew, MN; L. F. Tribble, TX; T. L. Veum, MO; J. T. Yen, ARS, and W. H. Pfander and M. E. Tumbleson, Administrative Advisors.

Received February 14, 1990.
Accepted June 19, 1990.

Downloaded from www.journalofanimalscience.org by guest on August 24, 2012

(1988) listed the biotin requirement of sows as 200 µg/kg, but stated that several factors "make it difficult to recommend a specific biotin requirement for sows."

The biotin content of corn is relatively low (70 to 110 µg/kg), but it seems to be 100% bioavailable to poultry (Frigg, 1976, 1984; Anderson et al., 1978; Buenrostro and Kratzer, 1984). Soybean meal is a relatively rich source of biotin (approximately 300 µg/kg) that also is reported to be 100% bioavailable to poultry (Buenrostro and Kratzer, 1984). Estimates of biotin bioavailability in pigs differ greatly. Sauer et al. (1988) determined that the digestibility of biotin at the terminal ileum was 4% for corn and 55% for soybean meal. In contrast, Misir and Blair (1988), using an assay based on plasma biotin, determined bioavailabilities of 101% for corn and 86% for soybean meal. Thus, the need for supplemental biotin in sow diets containing corn and soybean meal remains uncertain.

The purpose of the experiment reported herein was to investigate the need for biotin supplementation of corn-soybean meal diets fed to sows during gestation and lactation. To obtain a reasonably large number of animals and to evaluate the effect in various geographical regions, a coordinated experiment designed by the NCR-42 Committee on Swine Nutrition was conducted.

Experimental Procedures

This cooperative research involved 303 litters at three research stations in the north-central region of the U.S. The stations that participated in the study (and the specific locations) were Kentucky (Princeton), Minnesota (Grand Rapids) and Nebraska (Mead). The number of litters contributed by each station is listed in Table 1.

At each station, sows were allotted at breeding to two dietary treatments (control or biotin-supplemented). The allotment was at random within parity. The term "parity" refers to the lifetime parity of the sow (i.e., the total number of reproductive cycles, not the number of cycles during which they received the experimental diets). At Nebraska, sows were primiparous at the start of the experiment; at Kentucky and Minnesota, a combination of primiparous and multiparous sows was used. Sows were assigned to the same treatment for three successive reproductive cycles, but not all sows completed three cycles. The average parity of sows over the whole experiment was 2.82 (Table 1). Yorkshire sows were used at Kentucky, Landrace sows were used at Minnesota, and crossbred (Landrace × Large White × Hampshire × Duroc) sows were used at Nebraska.

Housing during gestation differed among the three stations. At Minnesota, sows were kept in individual stalls inside a building with concrete floors that were partially slatted. At Kentucky and Nebraska, sows were held in outside lots. At Kentucky, some vegetation was available to the sows during the summer. At Nebraska, the lots consisted of bare soil with concrete slabs. Essentially no vegetation was present; therefore, sows were not able to obtain supplemental biotin by grazing. During winter in Nebraska, the soil was often frozen, yielding a hard, rough and potentially abrasive surface. Sows at all three stations were housed in environmentally controlled buildings during farrowing and lactation.

Diets consisted of corn and soybean meal fortified with minerals and vitamins (Table 2). The control diet contained no supplemental biotin. Using values from ingredient composition tables (NRC, 1979), this diet contained 140 µg/kg biotin from corn and soybean meal. The biotin-supplemented diet contained an additional 330 µg/kg biotin from d-biotin. Both diets were formulated to contain 14% CP, .8% Ca and .7% P, and to meet or exceed NRC (1979) requirements for all other nutrients. No antibiotics were included in the diets.

The diets were fed during the gestation, lactation and weaning-to-breeding periods. Sows were fed 1.82 kg/d during gestation, except at Kentucky and Nebraska during December, January and February, when the feeding level was increased to 2.27 kg/d. All sows were allowed ad libitum access to feed during lactation; feed intakes were recorded.

Sows were weighed at breeding, on d 109 of gestation, within 24 h postpartum and on d 21 of lactation. Weight changes during gestation, from d 109 to postpartum, and during lactation (postpartum to d 21) were calculated.

The number of pigs farrowed (live and dead) and alive at d 21 of age was recorded for each litter. Pigs were weighed individually within 24 h postpartum and when 21 d old. Weaning age varied from 28 to 35 d (Table 1). A few pigs at Minnesota were crossfostered, but this was done only on a within-treatment basis.

Downloaded from www.journalofanimalscience.org by guest on August 24, 2012

TABLE 1. STATIONS AND NUMBER OF LITTERS INVOLVED IN THE EXPERIMENT

Station	No. of litters[a]	Breed of sows	Avg parity[b]	Weaning age, d
Kentucky	124	Yorkshire	2.97	35
Minnesota	69	Landrace	4.00	28
Nebraska	110	Crossbred	1.92	28

[a]A total of 303 litters, 157 in the control group and 146 in the biotin-supplemented group.

[b]Average parity of sows over the whole experiment. The average parity across the three stations was 2.82.

At weaning, the feet of sows were evaluated for lesions using the scoring system described by Bryant et al. (1985b). In the system used at Minnesota and Nebraska, the number and severity of horn cracks, heel cracks, sidewall cracks and bruises were recorded and reported separately. At Kentucky, these lesions were counted together and combined into a single overall lesion score.

Sows were rebred as soon as possible after weaning; the number of days from weaning to estrus was recorded. Any sow that did not exhibit estrus within 21 d of weaning was assigned a weaning-to-estrus interval of 21 d. Sows that did not conceive or were deemed unsound (severe feet and leg problems) were culled.

TABLE 2. COMPOSITION OF CONTROL DIET

Item	%
Ingredient	
Ground corn	81.1
Soybean meal (44% CP)[a]	15.5
Dicalcium phosphate	2.0
Ground limestone	.8
Salt	.4
Trace mineral mix[b]	.1
Vitamin mix[c]	.1
Calculated analysis[d]	
ME, kcal/kg	3,176
CP, %	14.0
Ca, %	.8
P, %	.7
Biotin, μg/kg	140

[a]At Minnesota, 46% CP soybean meal was used. The amount of corn was 81.8%, and the amount of soybean meal was 14.8%.

[b]Trace mineral mixes were different at each station, but all provided Zn, Fe, Mn, Cu, I and Se at levels such that diets met or exceeded NRC (1979) requirements.

[c]Vitamin mixes were different at each station, but all provided vitamins A, D, E, K and B_{12}, and riboflavin, pantothenic acid and niacin such that diets met or exceeded NRC (1979) requirements.

[d]Calculated from ingredient composition tables (NRC, 1979).

Data were analyzed by covariance procedures with litter as the experimental unit and parity as a covariate. The GLM procedure of SAS (1982) was used for the computations. The model included station, treatment and the station × treatment interaction. Pig weights at birth and at d 21 were analyzed with and without covariance adjustment for litter size. In these analyses, results obtained from the same sow in each farrowing (first, second or third) were regarded as independent observations. In a second set of analyses, the numbers of pigs born and alive at d 21 were analyzed separately for the first, second and third farrowing during which sows had received the experimental diets. The percentages of sows in each treatment group that exhibited estrus by d 7, 14 and 21 postweaning were compared using a nonparametric test of percentages (Koopmans, 1987). Station and parity were not included in these comparisons.

Results and Discussion

Differences existed ($P < .05$) among stations for most traits measured. These differences are indicated in the footnotes to Tables 3 through 7. Station differences are a common feature of cooperative experiments, and have been reported in previous research with sows conducted by the NCR-42 Committee (NCR-42, 1976; NCR-42, 1978) and by the S-145 Committee (Cromwell et al., 1989a,b). The only station × treatment interaction ($P < .10$) was for certain measures of foot lesions.

Biotin supplementation did not affect ($P > .15$) sow weights or sow weight changes from breeding to d 21 of lactation (Table 3). Other investigations of the need for supplemental biotin have also found no effect on sow weights (Grandhi and Strain, 1980; Easter et al., 1983; Simmins and Brooks, 1983; Hamilton and Veum, 1984; Tribble et al., 1984; Bryant et al., 1985c).

Downloaded from www.journalofanimalscience.org by guest on August 24, 2012

TABLE 3. EFFECT OF SUPPLEMENTAL BIOTIN DURING GESTATION AND LACTATION ON SOW WEIGHTS AND FEED INTAKES[abc]

	Supplemental biotin, μg/kg			
Item	0	330	*P*	CV
No. of litters	157	146		
Avg parity	2.80	2.84		
Sow wt, kg				
Breeding	158.0	160.2	.35	12.3
Day 109 of gestation	197.2	199.8	.39	12.3
Postpartum	183.8	185.2	.61	12.1
Day 21 of lactation	178.6	179.1	.85	12.6
Sow wt changes, kg				
Breeding to d 109	39.2	39.5	.83	34.8
Day 109 to postpartum	−13.4	−14.6	.18	52.1
Postpartum to d 21	−5.2	−6.1	.53	219.4
Gestation feed intake, kg/d	1.94	1.94	.76	7.4
Lactation feed intake, kg/d[d]	5.82	6.25	.24	50.7

[a]All means adjusted for parity.

[b]No station × treatment interactions ($P > .15$).

[c]Station effects ($P < .01$) for all traits except sow weight change from d 109 to postpartum.

[d]Data represent feed intake during the first 21 d of lactation.

Feed intake during gestation was regulated; consequently, the two treatments were not different. The mean gestation feeding level for the whole experiment was 1.94 kg/d. During lactation, the mean feed intake of sows fed the diet with supplemental biotin was .43 kg/d greater than that of sows fed the control diet. However, feed intake during lactation was quite variable (CV = 50.7%), so this difference was not significant ($P = .24$). Sows fed supplemental biotin nursed larger litters; this may have been the cause of the slight increase in feed intake.

Although the differences were not statistically significant, sows fed supplemental biotin farrowed more total pigs (11.28 vs 10.87; $P = .23$) and more live pigs (10.53 vs 10.10; $P = .19$) than sows fed the control diet (Table 4). Survival of pigs from birth to d 21 tended to be greater for litters of sows fed supplemental biotin (93.5 vs 88.9%; $P = .08$) than for controls. As a consequence, sows fed supple-

TABLE 4. EFFECT OF SUPPLEMENTAL BIOTIN DURING GESTATION AND LACTATION ON REPRODUCTIVE PERFORMANCE[abc]

	Supplemental biotin, μg/kg			
Item	0	330	*P*	CV
No. of litters	157	146		
Total pigs born	10.87	11.28	.23	25.6
Live pigs born	10.10	10.53	.19	25.9
Avg birth wt of live pigs, kg				
Unadjusted for litter size	1.42	1.44	.65	15.9
Adjusted for litter size	1.41	1.44	.20	13.8
Pigs at d 21	8.74	9.43	.01	24.4
Avg wt of pigs at d 21, kg				
Unadjusted for litter size	5.72	5.58	.21	16.7
Adjusted for litter size	5.66	5.64	.84	15.3
Pig survival to d 21, %	88.9	93.5	.08	24.3

[a]All means adjusted for parity.

[b]No station × treatment interactions ($P > .25$).

[c]Station effects ($P < .05$) for all traits except birth weight of live pigs (adjusted for litter size) and number of pigs at d 21.

Downloaded from www.journalofanimalscience.org by guest on August 24, 2012

TABLE 5. EFFECT OF SUPPLEMENTAL BIOTIN DURING GESTATION AND LACTATION AND DURATION OF THE TREATMENT ON REPRODUCTIVE PERFORMANCE[abc]

	Supplemental biotin, µg/kg			
Item	0	330	*P*	CV
First farrowing				
No. of litters	69	65		
Parity	2.01	2.14		
Total pigs born	11.03	11.30	.56	22.7
Live pigs born	10.24	10.75	.28	24.6
Pigs at d 21	8.70	9.69	.01	23.4
Second farrowing				
No. of litters	47	47		
Parity	2.94	3.09		
Total pigs born	10.62	10.59	.96	29.6
Live pigs born	9.75	9.75	.99	28.5
Pigs at d 21	8.66	9.01	.50	27.3
Third farrowing				
No. of litters	41	34		
Parity	3.98	3.85		
Total pigs born	10.92	12.22	.08	25.4
Live pigs born	10.44	11.17	.28	25.1
Pigs at d 21	9.05	9.55	.34	22.7

[a]All means adjusted for parity.

[b]No station × treatment interactions ($P > .35$).

[c]No station effects ($P > .05$) except total pigs born during the third farrowing ($P < .02$).

mental biotin had more pigs at d 21 (9.43 vs 8.74; $P = .01$) than their unsupplemented counterparts. Previous reports of beneficial effects of supplemental biotin on litter size at birth or weaning and(or) pig survival include those of Brooks et al. (1977), Penny et al. (1981), Easter et al. (1983), Simmins and Brooks (1983), Hamilton and Veum (1984), Tribble et al. (1984) and Misir and Blair (1986), although not all these effects were statistically significant. In contrast, no benefits were reported by Grandhi and Strain (1980) and Bryant et al. (1985c).

Biotin supplementation did not affect ($P > .20$) weight of pigs at birth or weaning, regardless of whether data were adjusted for differences in litter size. A lack of effect of supplemental biotin on pig weights has also been reported by Brooks et al. (1977), Grandhi and Strain (1980), Easter et al. (1983), Hamilton and Veum (1984) and Bryant et al. (1985c).

Data from each farrowing were analyzed separately (Table 5) to determine whether the increase in litter size in response to supplemental biotin was influenced by the length of time the sows received the diets. Although the largest difference in the number of live pigs born was in the third farrowing, no consistent trend emerged as the experiment progressed. Biotin-supplemented sows tended to have more pigs than controls at d 21 in each farrowing, but again no evidence indicated that the benefit became greater in later farrowings. In fact, the largest and only significant increase in the number of pigs at d 21 occurred during the first farrowing. Kornegay (1986) combined data from three experiments (Simmins and Brooks, 1983; Tribble et al., 1984; Bryant et al., 1985c) and presented evidence that the increase in live pigs farrowed caused by supplemental biotin was present only after the first parity. In the present research, both primiparous and multiparous sows were used, so a direct comparison with previous research in which only primiparous sows were used is not possible.

Biotin supplementation did not affect the length of the interval from weaning to estrus (Table 6). A reduced interval from weaning to estrus in response to supplemental biotin has been reported in some previous experiments (Brooks et al., 1977; Simmins and Brooks, 1983; Bryant et al., 1985c) but not in others (Grandhi and Strain, 1980; Penny et al., 1981; Tribble et al., 1984; Hamilton and Veum, 1984).

The effects of supplemental biotin on foot lesions are presented in Table 7. At Kentucky, no effects ($P > .20$) were noted on either the

Downloaded from www.journalofanimalscience.org by guest on August 24, 2012

TABLE 6. EFFECT OF SUPPLEMENTAL BIOTIN DURING GESTATION AND LACTATION ON THE INTERVAL FROM WEANING TO ESTRUS

Item	Supplemental biotin, μg/kg		P	CV
	0	330		
No. of sows	154	142		
Weaning to estrus interval, d[a]	6.45	6.04	.45	72.8
Percentage of sows exhibiting estrus				
Within 7 d	86	85	.39	
Within 14 d	91	92	.34	
Within 21 d	94	95	.28	

[a]Values were truncated at d 21 (i.e., values greater than 21 were recorded as 21). No station × treatment interaction ($P > .30$). Station effect ($P < .01$).

number of foot lesions or lesion scores, although the data tended to favor the biotin-supplemented group. The data collected at Minnesota and Nebraska, where cracks in various regions of the feet and bruises were examined separately, indicate that supplemental biotin did not reduce either the number or severity of feet cracks. In fact, for all categories of cracks, the incidence for sows receiving supplemental biotin was higher than for those whose diets were not supplemented. This difference was significant ($P = .08$) for the number of sidewall cracks. For this trait, however, a station × treatment interaction ($P < .05$) was found in which the number of sidewall cracks decreased in response to biotin at Minnesota but increased at Nebraska.

The incidence and severity of bruises was higher in the sows that received supplemental biotin than in the unsupplemented sows. For the number of foot bruises, evidence suggests a station × treatment interaction ($P < .10$) in

TABLE 7. EFFECT OF SUPPLEMENTAL BIOTIN DURING GESTATION AND LACTATION ON FOOT LESIONS[ab]

Item	Supplemental biotin, μg/kg		P	CV
	0	330		
Kentucky				
No. of observations	63	59		
No. of lesions[c]	2.59	2.40	.59	77.4
Overall lesion score[d]	1.20	1.07	.24	50.8
Minnesota and Nebraska				
No. of observations	93	86		
No. of horn cracks[c]	3.04	3.19	.68	91.8
Severity of horn cracks[e]	.91	.98	.51	78.5
No. of heel cracks[c]	2.86	3.03	.58	78.4
Severity of heel cracks[e]	1.19	1.14	.72	81.6
No. of sidewall cracks[c]	3.57	4.57	.08[f]	86.7
Severity of sidewall cracks[e]	1.27	1.44	.19[g]	60.2
No. of bruises[c]	.87	1.40	.01[g]	122.4
Severity of bruises[e]	.52	.93	.01	117.0

[a]All means adjusted for parity.

[b]Station effects between Minnesota and Nebraska ($P < .01$) for all traits except severity of sidewall cracks.

[c]Values represent the total number of lesions for all four feet.

[d]Lesion score based on the overall condition of the feet where 0 represents no lesions and 5 represents many severe lesions.

[e]The scoring system of Bryant et al. (1985a) was used, where "each lesion was given a severity score ranging from 1 to 5, with 1 indicating a very small lesion and 5 a very large severe lesion."

[f]Station × treatment interaction, $P < .05$.

[g]Station × treatment interaction, $P < .10$.

Downloaded from www.journalofanimalscience.org by guest on August 24, 2012

which the increase in number of foot bruises was greater at Minnesota than Nebraska. Bryant et al. (1985a) found that supplemental biotin decreased the incidence and severity of all types of foot cracks but increased the incidence of bruises by 16%, although this increase was not statistically significant. Similarly, Simmins and Brooks (1988) presented data indicating that biotin supplementation of sow diets decreased the incidence of cracks in foot claws but increased the incidence of heel cuts. Sows fed diets with supplemental biotin had more ($P < .01$) bruises and abrasions of the heel than did control sows after the first and second farrowings, but less ($P < .05$) than control sows after the third and fourth farrowings. Kornegay (1986) reviewed evidence that biotin increases the hardness of the hoof wall but decreases the hardness of heel bulb tissue. Perhaps biotin supplementation could decrease the incidence of foot cracks and increase the incidence of foot bruises.

We cannot draw unequivocal conclusions about the overall effect of supplemental biotin on foot lesions; no clear evidence indicated that the addition of biotin reduced either the incidence or severity of foot lesions in this experiment. The overall severity of foot lesions was lower than in some previous experiments; this may have been partially responsible for the equivocal results. The effect on foot lesions remains one of the more controversial benefits that have been attributed to supplemental biotin. A comprehensive review of this subject was presented by Kornegay (1986).

Implications

Reproductive performance of sows, specifically the number of pigs at d 21 of lactation, was improved by adding 330 μg/kg supplemental biotin to a corn-soybean meal diet. Because only one level of supplemental biotin was tested, no estimate of the biotin requirement can be made except that it exceeds the amount present in the control diet (140 μg/kg). Biotin did not prevent or improve cracks and bruises on the feet of sows.

Literature Cited

Anderson, P. A., D. H. Baker and S. P. Mistry. 1978. Bioassay determination of the biotin content of corn, barley, sorghum and wheat. J. Anim. Sci. 47:654.

Brooks, P. H., D. A. Smith and V.C.R. Irwin. 1977. Biotin-supplementation of diets; the incidence of foot lesions, and the reproductive performance of sows. Vet. Rec. 101:46.

Bryant, K. L., E. T. Kornegay, J. W. Knight, H. P. Veit and D. R. Notter. 1985a. Supplemental biotin for swine. III. Influence of supplementation to corn- and wheat-based diets on the incidence and severity of toe lesions, hair and skin characteristics and structural soundness of sows housed in confinement during four parities. J. Anim. Sci. 60:154.

Bryant, K. L., E. T. Kornegay, J. W. Knight, K. E. Webb, Jr. and D. R. Notter. 1985b. Supplemental biotin for swine. I. Influence on feedlot performance, plasma biotin and toe lesions in developing gilts. J. Anim. Sci. 60:136.

Bryant, K. L., E. T. Kornegay, J. W. Knight, K. E. Webb, Jr. and D. R. Notter. 1985c. Supplemental biotin for swine. II. Influence of supplementation to corn- and wheat-based diets on reproductive performance and various biochemical criteria of sows during four parities. J. Anim. Sci. 60:145.

Buenrostro, J. L. and F. H. Kratzer. 1984. Use of plasma and egg yolk biotin of White Leghorn hens to assess biotin availability from feedstuffs. Poult. Sci. 63:1563.

Cromwell, G. L., D. D. Hall, A. J. Clawson, G. E. Combs, D. A. Knabe, C. V. Maxwell, P. R. Noland, D. E. Orr and T. J. Prince. 1989a. Effects of additional feed during late gestation on reproductive performance of sows: a cooperative study. J. Anim. Sci. 67:3.

Cromwell, G. L., D. D. Hall, G. E. Combs, O. M. Hale, D. L. Handlin, J. P. Hitchcock, D. A. Knabe, E. T. Kornegay, M. D. Lindemann, C. V. Maxwell and T. J. Prince. 1989b. Effects of dietary salt level during gestation and lactation on reproductive performance of sows: a cooperative study. J. Anim. Sci. 67:374.

Easter, R. A., P. A. Anderson, E. J. Michel and J. R. Corley. 1983. Response of gestating gilts and starter, grower and finisher swine to biotin, pyridoxine, folacin and thiamine additions to corn-soybean meal diets. Nutr. Rep. Int. 28:945.

Frigg, M. 1976. Bio-availability of biotin in cereals. Poult. Sci. 55:2310.

Frigg, M. 1984. Available biotin content of various feed ingredients. Poult. Sci. 63:750.

Grandhi, R. R. and J. H. Strain. 1980. Effect of biotin supplementation on reproductive performance and foot lesions in swine. Can. J. Anim. Sci. 60:961.

Hamilton, C. R. and T. L. Veum. 1984. Response of sows and litters to added dietary biotin in environmentally regulated facilities. J. Anim. Sci. 59:151.

Koopmans, L. H. 1987. An Introduction to Contemporary Statistical Methods (2nd Ed.). Duxbury Press, Boston, MA.

Kornegay, E. T. 1986. Biotin in swine production: A review. Livest. Prod. Sci. 14:65.

Misir, R. and R. Blair. 1986. Reproductive performance of gilts and sows as affected by induced biotin deficiency and subsequent dietary biotin supplementation. J. Anim. Physiol. Anim. Nutr. 55:196.

Misir, R. and R. Blair. 1988a. Biotin bioavailability from protein supplements and cereal grains for weanling pigs. Can. J. Anim. Sci. 68:523.

NCR-42 Committee on Swine Nutrition. 1976. Effect of supplemental choline on reproductive performance of sows: A cooperative regional study. J. Anim. Sci. 42: 1211.

NCR-42 Committee on Swine Nutrition. 1978. Effect of

Downloaded from www.journalofanimalscience.org by guest on August 24, 2012

protein level during gestation and lactation on reproductive performance in swine. J. Anim. Sci. 46: 1673.

NRC. 1979. Nutrient Requirements of Swine (8th Ed.). National Academy Press, Washington, DC.

NRC. 1988. Nutrient Requirements of Swine (9th Ed.). National Academy Press, Washington, DC.

Penny, R.H.C., R.D.A. Cameron, S. Johnson, P. J. Kenyon, H. A. Smith, A.W.P. Bell, J.P.L. Cole and J. Taylor. 1981. Influence of biotin supplementation on sow reproductive efficiency. Vet. Rec. 109:80.

SAS. 1982. SAS User's Guide: Statistics. SAS Inst., Inc., Cary, NC.

Sauer, W. C., R. Mosenthin and L. Ozimek. 1988. The digestibility of biotin in protein supplements and cereal grains for growing pigs. J. Anim. Sci. 66:2583.

Simmins, P. H. and P. H. Brooks. 1983. Supplementary biotin for sows: effect on reproductive characteristics. Vet. Rec. 112:425.

Simmins, P. H. and P. H. Brooks. 1988. Supplementary biotin for sows: effect on claw integrity. Vet. Rec. 122: 431.

Tribble, L. F., J. D. Hancock and D. E. Orr, Jr. 1984. Value of supplemental biotin on reproductive performance of sows in confinement. J. Anim. Sci. 59(Suppl. 1): 245(Abstr.).

Downloaded from www.journalofanimalscience.org by guest on August 24, 2012

Citations This article has been cited by 4 HighWire-hosted articles:
http://www.journalofanimalscience.org/content/69/1/207#otherarticles

Downloaded from www.journalofanimalscience.org by guest on August 24, 2012