Virginia Journal of Science
Volume 44, Number 4
Winter 1993

Progeny Response And Metabolite Changes In Gestating And Lactating Gilts Fed High Fructose-Corn Syrup[1]

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ABSTRACT

Pregnant gilts were fed a diet containing 17.9% fructose beginning at d 30 of gestation to study the influence of fructose-corn syrup on serum metabolites, farrowing characteristics and progeny performance. Gilts were bled at 28-d intervals during gestation and on d 14 and 35 of lactation. Diet and stage of gestation affected ($P < 0.01$) serum glucose and fructose levels of the gilts during the treatment period. No significant differences ($P > 0.05$) were observed on serum metabolites and insulin levels during the first 58 days. Serum glucose levels rose significantly ($P < 0.01$) after d 86 of gestation, reaching its peak after 112 d of gestation and remaining high throughout lactation in the fructose-fed group. Dietary fructose did not significantly ($P > 0.05$) influence serum insulin levels. However, the change in insulin levels over the treatment period was significant ($P < 0.05$). Serum triglyceride, free fatty acids and cholesterol were unaffected. Liver weight of progeny at birth and liver glycogen concentrations remained unchanged. Hourly milk yield in gilts, litter size and weight and progeny survival at birth and at d 35 were not affected ($P > 0.05$) by maternal diet. The results indicated that fructose diet increased serum fructose and glucose concentrations only during late gestation and lactation but did not influence the progeny energy reserves or neonatal pig performance.

Key Words: Gilt, gestation, metabolites, progeny, lactation, fructose, diet.

INTRODUCTION

Elevating blood glucose concentrations or sparing glucose in gestating sows can be beneficial to fetal pigs by increasing nutrient supply to the developing pigs for growth, liver glycogen deposition, and/or lipid synthesis. Fetuses and piglets from gilts made diabetic via alloxan or streptozotocin injection showed significant elevation of liver weight, liver glycogen content and body lipid (Ezekwe, et al, 1984; Ezekwe, 1986) as well as demonstrated an improvement in postnatal survival (Kasser, et al., 1982).

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3 The use of any trade names of vensdrs does not imply approval to the exclusion of other products or vendors that may also be suitable.

Since crystalline fructose and fructose-corn syrup have become available, a number of studies have shown that sows fed fructose showed significant elevation of blood glucose and fructose concentrations, while maintaining lower insulin concentrations (White et al., 1987). Milk yield from these fructose-fed sows increased, and body weight of pigs at weaning were heavier than controls. The authors suggested that the dietary fructose may have served as a precursor for milk constituents and thus spared glucose. However, other reports showed that a fructose diet fed during late gestation and lactation did not influence sow metabolite profile, insulin levels, or milk yield (Coffey et al., 1987; Kveragas, et al., 1988). These studies were conducted during the third trimester of gestation or lactation when the sows' metabolite profile was greatly influenced by gestational or lactational stress. No information is available on the effects of fructose diet on maternal serum metabolites during the first and second trimester of gestation. The objective of this study was to determine the influence of fructose-corn syrup, beginning at d 30 of gestation and throughout lactation, on the gilt blood metabolite and insulin concentrations, milk yield, farrowing performance characteristics, piglet energy reserves, and survival.

MATERIALS AND METHODS

Twelve pregnant crossbred gilts (Duroc x Yorkshire x Landrace) with known breeding dates were assigned to two treatment groups. Gilts were weighed and randomly allotted to control and fructose fed groups, respectively. Animals were fed 1.82 kg/d of corn-soybean meal diet containing 14% protein and adequately fortified with vitamins and minerals to meet the NRC (1979) nutrient requirements for gestating swine (Table 1). The fructose-fed group received the same diet but with 32.5% of the carbohydrate portion replaced with fructose-corn syrup (American Sweeteners Inc., Frazer, PA). The experimental diet was essentially isocaloric and iso-nitrogenous and the fructose diet was formulated to contain 17.9% fructose similar to levels used by White et al; (1984, 1987).

Blood was taken by venapuncture from the anterior vena cava of all the animals before the initiation of treatments and at 28-d intervals until parturition. During lactation, blood was collected from the gilts at d 14 and 35 of lactation. All gilts were meal-fed and blood was collected about 2 h after each feeding. Serum was collected after centrifugation and frozen at -20C until analyzed for glucose, cholesterol and triglycerides (Sigma Tech. Bul. #510, 352 and 405, respectively. Sigma Chemical Co.; St. Louis, MO.). Serum free fatty acids (FFA) were assayed according to methods of Dunocombe (1963, 1964). The lower range of sensitivity for the assay was 10 μEq/L of serum. Serum insulin was determined by double antibody radioimmunoassay techniques using an assay kit supplied by Cambridge Medical Diagnostic (Cambridge Medical Diagnostics, Billerica, MASS.) with a lower range of sensitivity of 5 μU/mL of serum. Intra-assay coefficient of variation was 11%. Serum fructose was assayed according to the resorcinol method of Roe (1954) as modified by Arsenault and Yaphe (1965).

All farrowings were attended. At parturition, pigs were cleaned and weighed and 1 or 2 pigs/litter with or near the average body weight of the litter were mechanically stunned and killed by exsanguination. Blood was collected, serum harvested and frozen for later biochemical determinations. The liver was removed,

TABLE 1. Composition of control and fructose diet[a]

Item	Control Diet g/100g	Fructose Diet g/100g
Corn (IFN 4-02-935)	79.16	48.48
Soybean Meal, 48% CP (IFN 5-04-612)	12.69	18.37
Fructose Corn Syrup[b]	--	32.5
Tallow	1.5	--
Alfafa (IFN 1-00-023)	5.00	5.00
Dicalcium Phosphate (IFN 6-01-080)	1.00	1.00
Limestone (IFN 6-01-069)	0.90	0.90
Trace Mineral Salt[c]	0.50	0.50
Salt (IFN 6-14-013)	0.50	0.50
Vitamin Premix[d]	0.25	0.25
ME, Kcal/kg	3365	3373

[a]Calculated to contain 14% crude protein
[b]American Sweeteners Inc., Frazer, Pa. High fructose corn syrup contains 55% fructose on dry matter basis added to diet to supply 17.9% fructose
[c]Contained (%) 17.5 Zn; 14 Mn; 8.8 Fe; 1.7 Cu; 0.35 I and 0.35 Co
[d]Supplied (per kg of premix) 1.76 g riboflavin; 8.8 g panthothenic acid; 8.8 g niacin; 8.8 mg vitamin A; 176,000 I.U. vitamin D; 4400 I.U. vitamin E; 440 mg menadione dimethylprimidinol bisulfite; 88.2 mg biotin and 40 mg Se

bloted dry and weighed. A piece was cut out in triplicate immediately digested in 30% KOH saturated with Na_2SO_4 for glycogen determination according to methods of Lo et al. The remaining litters were equalized to 7 or 8 pigs and allowed to suckle the dams. Gilts were fed about 5.4 kg/day during lactation and the amount fed was scaled to the number of pigs nursed. Creep feed was not provided to the pigs; however, pigs had access to the sows' diet before weaning. Survival of pigs and body weight at birth and at weaning were recorded. Milk yield was estimated at d 14 of lactation by the weigh-suckle-weigh method (Speer and Cos, 1984).

Statistical evaluation was done by one-way analysis of variance (Steel and Torrie, 1960). A 2 x 6 factorial analysis of variance was used to determine the effect of diet and gestational/lactational stage (time) on sow blood metabolites and insulin. Treatment means were separated by the least significant difference (LSD) technique.

TABLE 2. Reproductive performance and milk yield in fructose-fed and control gilts[a]

CHARACTERISTIC[b]	TREATMENT	
	CONTROL	FRUCTOSE
Gestation Length, d	114.6 ± 0.3	114.4 ± 0.2
Wt. at d 30, kg	138.8 ± 10.8	142.8 ± 8.2
Wt. at d 112, kg	166.8 ± 11.8	175.2 ± 8.1
Wt at d 35 of lactation, kg	155.7 ± 2.1	163.5 ± 9.2
Litter size	10.5 ± 1.2	8.5 ± 0.8
Litter wt at birth, kg	11.2 ± 0.9	10.4 ± 0.53
Litter wt at d 35 of lactation, kg	032.7 ± 5.6	37.2 ± 1.3
Survival at birth, %	90.1 ± 7.5	95.6 ± 2.4
Survival at d 35 of lactation	69.5 ± 9.4	84.1 ± 6.5
Hourly milk yield, g	249.3 ± 60.4	267.6 ± 71.0

[a]Mean ± SEM for 6 animals
[b]Control and fructose groups did not differ ($P > 0.05$)

RESULTS

Table 2 represents the reproductive performance characteristics and hourly milk yield of the fructose-fed and control gilts. There were no differences ($P > 0.05$) in gestation length, gilt weight gain during gestation, or weight at weaning. Litter size and weight at birth were not significantly affected by treatment. Although litter weight at weaning, litter survival (birth and weaning) and milk yield were slightly higher in fructose fed gilts, these trends were not statistically significant ($P > 0.05$).

The effect of dietary fructose during gestation and lactation on blood glucose and fructose concentrations is shown in Figure 1 and 2. Diet and stage of gestation affected ($P < 0.01$) serum glucose and fructose levels during the treatment period. Serum glucose levels rose significantly ($P < 0.01$) after d 86 of gestation, reaching a peak at d 112 of gestation, and remaining high throughout lactation in fructose-fed dams. Fructose levels exhibited elevated concentrations ($P < 0.01$) at d 112 of gestation and throughout lactation in the fructose fed group. Serum glucose and fructose levels in the fructose fed dams were affected ($P < 0.05$) by the stage of gestation (time). There was a diet by stage-of- gestation/lactation interaction ($P < 0.05$) for serum glucose and fructose.

Dietary fructose did not affect ($P > 0.05$) serum insulin levels (Figure 3). However, the change in insulin levels over the treatment period was significant ($P < 0.05$). Cholesterol, triglycerides and free fatty acids were not significantly ($P > 0.05$) influenced by diet (Figures 4, 5 & 6).

Stage of gestation/lactation did not influence ($P > 0.05$) serum triglyceride, cholesterol or free fatty acids levels. Peak levels of triglycerides were reached at d 112 of gestation and decreased by d 14 of lactation (Figure 5). The progeny performance characteristics did not show significant differences between fructose-

TABLE 3. Serum and liver metabolite levels in progeny of fructose-fed and control gilts at birth[a]

ITEM[b]	TREATMENT	
	CONTROL	FRUCTOSE
Glucose, mg/dL	88.3 ± 18.0	106.3 ± 18. 0
Fructose, mg/dL	25.2 ± 9.0	36.0 ± 10.2
Triglycerides, mg/dL	53.1 ± 17.7	79.7 ± 26.6
Free fatty acid, %Eq/L	462.1 ±100.7	333.1 ±100.7
Cholesterol, mg/dL	40.2 ± 3.6	32.5 ± 3.6
Glycogen, mg/g	88.4 ± 12.0	99.8 ± 11.4
Liver wt, g	32.7 ± 3.8	30.9 ± 1.8

[a]Mean ± SEM for 7 piglets
[b]Did not differ ($P > 0.05$)

fed and control pigs (Table 3). Progeny serum metabolites as well as liver weight and liver glycogen concentrations were not influenced significantly ($P > 0.05$) by maternal prepartum diet. There was a trend ($P < 0.06$) toward elevated serum glucose levels in progeny of fructose-fed dams at birth.

DISCUSSION

Results demonstrated that the ability of a fructose diet to alter maternal serum glucose in gestating gilts depended on the stage of gestation. A number of studies involving fructose feeding to gestating and/or lactating sows have shown that a fructose diet increased (White et al., 1984; 1987) or did not affect serum glucose (Coffey et al., 1987; Kveragas et al., 1988). The present study showed that a fructose diet failed to increase maternal serum glucose in early and mid-gestation in gilts, while a significant increase was observed during late gestation and lactation. It is not clear whether the observed response was due primarily to the physiological state of the animal or to the fructose diet *per se*. The high concentration of serum fructose in treated animals during late gestation indicated that carboydrate metabolism was being influence by late gestational physiology. Kveragas et al; (1988) showed no change in mean concentrations of glucose overtime in sow plasma as a result of dietary fructose fed during gestation. In the present study, while fructose diet failed to increase serum glucose during the early and mid gestation, serum glucose was markedly elevated during late gestation in respone to fructose feeding. In both Kveragas et al., (1988) and the present study, blood fructose concentrations were significantly increased. White et al, (1984) showed that maximum glucose stimulation was reached two hours after feeding, suggesting that the time between feeding and blood sampling might affect the concentration of metabolites. The low serum fructose concentrations in control gilts were in agreement with those reported for sows (Randal L'Ecuyer, 1976).

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[a]Mean ± SEM for 7 piglets
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Significant correlation between glucose and fructose reported by White et al; (1987) suggests that either fructose is converted to glucose in vivo or fructose has a glucose-sparing effect. Numerous studies in humans, calves and pigs showed that only very small amounts of fructose to glucose conversion occurred (Edwards and Powers, 1967; Dunningam and Ford, 1975; Aitken et al., 1972). It is likely that hormones mediate the dietary fructose alteration of carbohydrate metabolism by increasing glucose production and decreasing its clearance from circulation. Burt and Pulliam, (1960) suggested that increased glucocorticoids in late pregnancy might be involved. In humans, a proteolytic enzyme capable of inactivating insulin has been identified in placental membrances (Frienkel and Goodner, 1960). These factors may contribute to insulin resistance and the tendency for insulin to increase (Figure 2) with the increase in glucose concentration often referred to as gestational diabetes. Though diet did not influence serum insulin concentration in the present studies, serum insulin increased ($P < 0.05$) with time during the experiment with increasing glucose concentration. Serum insulin was decreased (White et al, 1984; 1987) or unaffected (Coffey et al., 1987; Kveragas et al, 1988) by fructose diet fed to gestating and/or lactating sows.

The lack of significant differences in reproductive performance characteristics and progeny performance (Table 3) indicates that the observed maternal nutrient alterations may not have reached the critical level needed to alter fetal metabolism. Glucose crosses the placenta by facilitated diffusion against a concentration gradient (Widdas, 1961). When the maternal level of plasma glucose is normal, the "fetal diet" contains a relatively large amount of glucose capable of sustaining 50-70% of fetal oxidative requirements (Battaglia and Meschia, 1978). Milk yields did not differ significantly ($P > 0.05$). Higher milk yield from sows fed fructose during lactation was reported in previous studies by White et al, (1987). On the other hand, Kveragas et al (1988); and Coffey et al., (1987) reported no increases in milk yield when sows were fed fructose during late gestation and lactation.

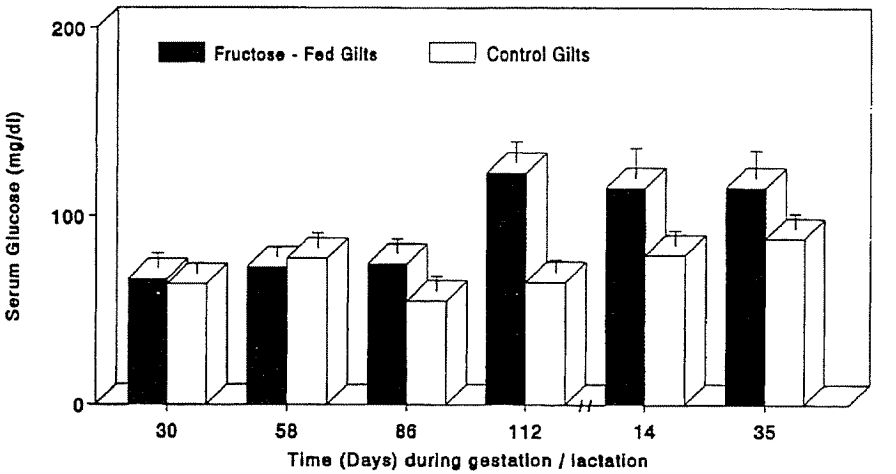

FIGURE 1. Effect of high fructose diet during gestation and lactation on serum glucose concentrations in gilts. Pregnant gilts were fed either control or high fructose (17.9% of diet composition) diet during gestation and lactation. Blood was sampled from the animals prior to initiation of experimental treatments (d 30 of gestation) and subsequently at 28-d intervals and on d 14, and 35 of lactation. ANOVA indicated a significant ($P < 0.01$) effect of diet and stage of gestation/lactation on glucose concentrations during the study. There was a diet by stage of gestation lactation interaction ($P < 0.05$) for serum glucose and fructose of the gilts.

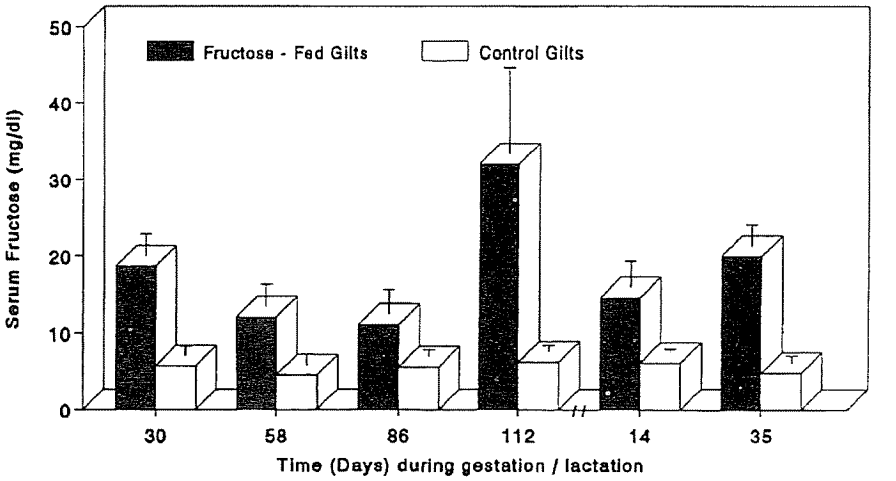

FIGURE 2. Effect of high fructose diet during gestation and lactation on serum fructose concentrations in gilts. ANOVA indicated a significant ($P < 0.01$) effect of diet and stage of gestation/lactation on fructose concentrations during the study. Diet by stage of gestation/lcatation interaction ($P < 0.05$) was observed in the animals.

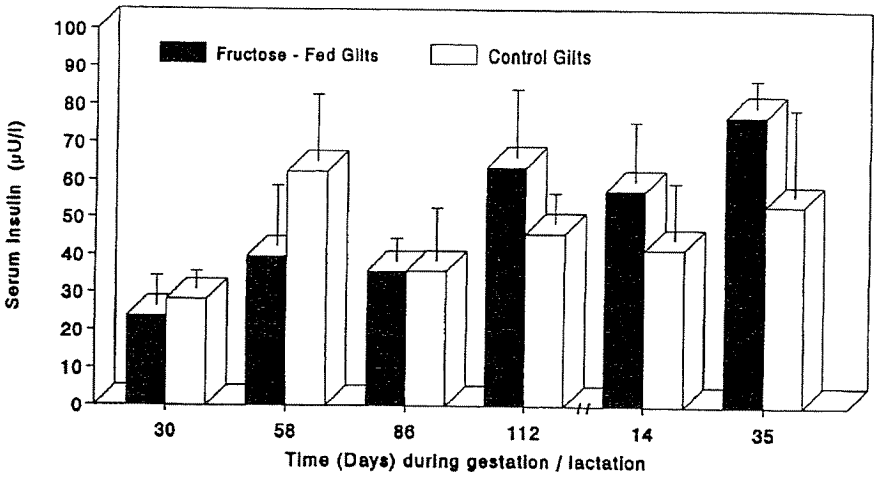

FIGURE 3. Effect of high fructose diet during gestation and lactation on serum insulin concentrations in gilts. ANOVA revealed no significant ($P > 0.05$) effect of diet, however stage of gestation/lactation (time) influenced ($P < 0.05$) serum insulin concentrations.

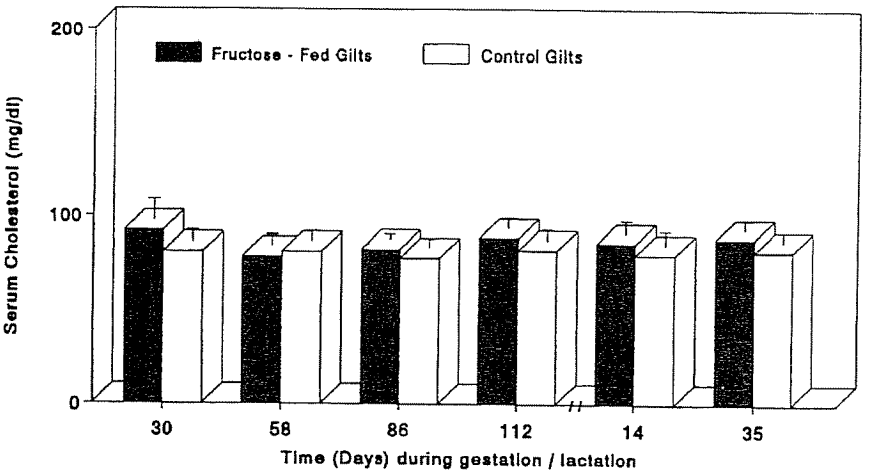

FIGURE 4. Mean concentration of serum cholesterol in gilts fed high fructose and control diet during gestation and lactation. ANOVA indicated no significant effect of diet and stage of gestation/lactation on serum cholesterol levels.

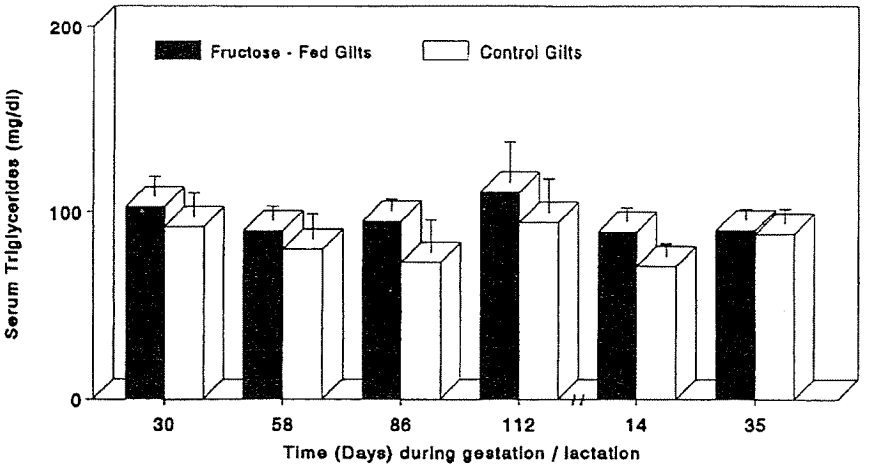

FIGURE 5. Mean serum triglyceride concentrations in gilts fed high fructose and control diet during gestation and lactation. ANOVA showed no significant diet and stage of gestation/lactation effect on serum triglyceride concentrations of gilts.

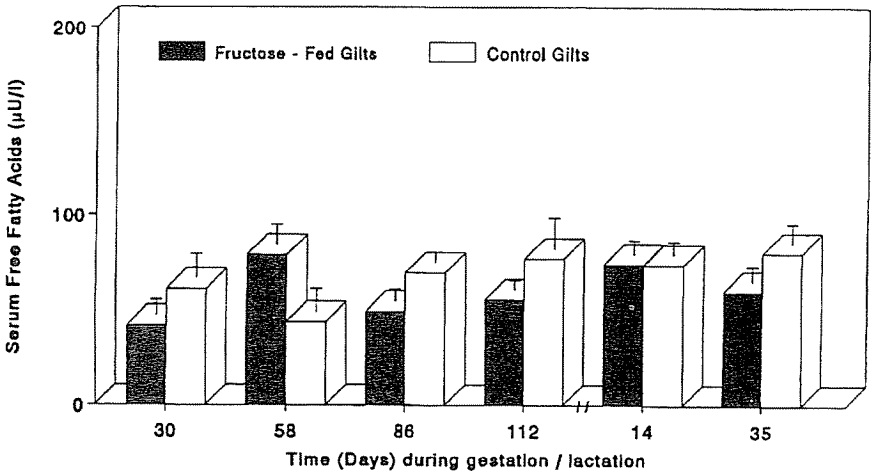

FIGURE 6. Effect of dietary fructose on serum free fatty acids concentrations in gilts during gestation and lactation. ANOVA indicated no significant ($P > 0.05$) effect of diet and stage of gestation/lactation on serum free fatty acids concentrations of the gilts.

Positive correlations between pig weaning weights and sow milk yield have been reported (Boyd et al., 1978).

Although glucose concentrations were high in fructose-fed gilts, we do not know if the level was sustained long enough to affect fetal liver glycogen synthesis. Glycogen storage depends on the availability of sufficient glucose substrate. The fluctuations in cholesterol, FFA and triglycerides may be indicative of normal variations in circulating metabolites rather than treatment effects.

This study showed that extended feeding of fructose diet does not influence the metabolite status of pregnant gilts during early or mid-gestation. While, serum glucose and fructose levels were significantly higher in fructose-fed gilts, no factors related to piglet survival were influenced by maternal diet. The fact that gilts were unresponsive to fructose diet during early and mid-gestation, suggests that factors other than fructose may be responsible for the stimulation of serum glucose and fructose concentrations during late gestation. It would appear that the real predisposing factor was the diabetic-like state which was evident during late gestation and lactation. This study indicated that late gestation was an ideal time to manipulate the sow's metabolism in favor of fetal development.

ACKNOWLEDGMENT

This study was supported by the USDA-CSRS. I greatly appreciate the contributions of Ella-Mai McBorrough in blood collection and analysis, as well as in the initial summary of the data.

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