

**ENERGY METABOLISM AND LACTATION PERFORMANCE OF  
PRIMIPAROUS SOWS AS AFFECTED BY DIETARY FAT  
AND VITAMIN E**

CENTRALE LANDBOUWCATALOGUS



0000 0489 4388

**Promotor:** dr. ir. M.W.A. Verstegen  
buitengewoon hoogleraar op het vakgebied van de veevoeding in het  
bijzonder de voeding van de eenmagigen

**Co-promotor:** dr. ir. L.A. den Hartog  
directeur van het Proefstation voor de Varkenshouderij  
te Rosmalen

UN08201,7496

**L. Babinszky**

**ENERGY METABOLISM AND LACTATION PERFORMANCE OF  
PRIMIPAROUS SOWS AS AFFECTED BY DIETARY FAT  
AND VITAMIN E**

**Proefschrift**

ter verkrijging van de graad van  
doctor in de landbouw- en milieuwetenschappen,  
op gezag van de rector magnificus,  
dr. H.C. van der Plas,  
in het openbaar te verdedigen  
op donderdag 7 mei 1992  
des namiddags te vier uur in de aula  
van de Landbouwniversiteit te Wageningen.

200819022

BIBLIOTHEEK  
LANDBOUWUNIVERSITEIT  
WAGENINGEN

**Babinszky, L. 1992. Energy metabolism and lactation performance of primiparous sows as affected by dietary fat and vitamin E.** In this thesis different levels of dietary fat (37, 43, 75 and 125 g/kg DM, respectively) and vitamin E (from 14 to 151 mg  $\alpha$ -tocopherol/kg diet) in the lactation diet, were studied for their effect on the energy metabolism, and lactation performance of primiparous sows. The effects of different levels of vitamin E (13, 48 and 136 mg  $\alpha$ -tocopherol/kg diet, respectively) and types of dietary fat (50 g/kg sunflower oil or animal fat) in gestation and lactation diets, on some immunological parameters of sows and piglets were also investigated. It was found that a high level of fat in the lactation diet decreased daily heat production of sows. As a consequence the energetic efficiency of milk production was improved. A high dietary fat level increased the milk fat output. The daily quantity of milk from sows was not influenced by the different levels of dietary fat, nor by the vitamin E in the diet. The high level of dietary vitamin E in the pregnancy and lactation diets had no consistent effect on the measured parameters of the cell-mediated and humoral immunity of lactating sows. The results of present studies indicate that vitamin E levels in sows' diets can improve some immunological variables in piglets. The fat sources had no consistent effect on the immunological parameters tested.

**Ph.D. Thesis, Department of Animal Nutrition, Wageningen Agricultural University, Haagsteeg 4, 6708 PM Wageningen, The Netherlands.**

*To my wife Margit,  
our son Tamás,  
and my parents*

## Voorwoord

Dit proefschrift is het resultaat van onderzoeken gedaan bij de vakgroep Veevoeding van de Landbouwwuniversiteit. Een deel van de proeven werd uitgevoerd in samenwerking met de vakgroep Veehouderij. Vanaf deze plaats wil ik een woord van dank richten aan iedereen die een bijdrage heeft geleverd aan de totstandkoming van dit proefschrift.

Allereerst wil ik mijn promotor, prof. dr. ir. M. W. A. Verstegen, en mijn co-promotor, dr. ir. L. A. den Hartog, bedanken voor de geboden mogelijkheid om deze onderzoeken te verrichten en voor hun enthousiasme en bereidheid om over de resultaten en de manuscripten te discussiëren. Het werken met hen was niet alleen bijzonder stimulerend, maar ook heel gezellig.

Zonder de hulp van een groot aantal mensen zou dit proefschrift niet tot stand zijn gekomen.

Hartelijk dank aan alle medewerkers van de vakgroep Veevoeding voor de verzorging van de dieren tijdens het afbiggen en voor de hulp in de stal ("baby-sit ploegendienst").

Tevens wil ik de mensen bedanken voor hun hulp bij het analyseren van het oneindige aantal monsters, nl.: Ellen Harmsen, Kam Mok, Ger de Vries-Reilingh, Jane-Martine Muylaert, Truus Post, Marianne van't End en Kees Oskam.

In het bijzonder wil ik dr. ir. Huug Boer en ing. Mike Nieuwland bedanken voor de begeleiding in het laboratorium.

De medewerkers van de proefaccomodatie "De Haar", Zodiac dank ik voor hun inzet.

Dr. ir. Bas Kemp, ir. Karel de Greef en ing. Peter van der Togt dank ik voor de discussie en hulp bij de statistische analyse en de hulp bij het gebruik van de PC.

Ing. Tammé Zandstra dank ik voor zijn bijzonder grote bijdrage aan het onderzoek. Zonder zijn hulp bij de uitvoering van de proeven en het organiseren van vele zaken, zou dit onderzoek onmogelijk zijn geweest.

Vele studenten hebben voor hun doctoraalstudie in dit onderzoek geparticipeerd. Leerzame discussies naast gezellige uren in de stal en op het lab hielden de stemming erin. Daarvoor mijn dank aan: Pim Langhout, Harry Boshouwers, Peter Bakker, Jos Verstegen, Edward van Elsen, Hans van Dam en Piet Donkers.

Verder dank ik Josien van de Kraats-Bos en Maria Lippelt-Rutten voor de goede administratieve hulp.

De onderzoeken beschreven in de hoofdstukken 1, 2 en 3 zijn uitgevoerd in de klimaatrespiratiekamers van de proefaccomodatie "De Haar", Zodiac. Ing. Prins van der Hel, Koos van der Linden, ing. Marcel Heetkamp, ir. Henk Brandsma, ir. Jos Gorssen en Peter Vos dank ik voor de goede begeleiding bij het werken en de prettige en succesvolle samenwerking.

Ik wil ook dank uitbrengen aan dr. Piet Joling. Zijn bijdrage aan de discussies en het kritisch

## STELLINGEN

### I

**An increase in the fat level in an isocaloric lactation diet will decrease the daily heat production of sows.**

**(This thesis)**

### II

**The efficiency of milk production from dietary metabolizable energy above maintenance requirement is improved when sows are fed a high level of dietary fat.**

**(This thesis)**

### III

**The suckling itself is very costly energetically. It requires about two times more energy than the mean level of daily heat production of piglets.**

**(This thesis)**

### IV

**A high level of vitamin E in the sow's diet during lactation can increase the antibody production against ovalbumin in weaned piglets.**

**(This thesis)**

### V

**The diet should be the primary source of vitamin E for lactating sows, and suckling and weaned piglets.**

**(This thesis and D.C. Mahan, 1991. J. Anim. Sci., 69: 2904-2917.)**

### VI

**For milk fat synthesis, fat content of the diet does not need to exceed 11%.**

## VII

**Extra digestible fat in the lactation diet can be beneficial in a warm environment.**

## VIII

**Wijsheid komt niet alleen uit ervaring. Dan zijn we net als de kat die op een heet kacheldeksel gaat zitten. Dat zal ze niet voor een tweede keer doen, maar ze zal ook nooit meer op een koud kacheldeksel gaan zitten. (naar Mark Twain)**

## IX

**Als u zegt dat iemand gevoel voor humor heeft, bedoelt u dan dat u om hem moet lachen of dat hij uw grappen begrijpt? (Max Frisch)**

## X

**De poorten van het uitblinken worden omgeven door een zee van zweet.**

**Proefschrift van L. Babinszky: "Energy metabolism and lactation performance of primiparous sows as affected by dietary fat and vitamin E".**

**Wageningen, 7 mei 1992**

becommentariëren van het manuscript heb ik zeer gewaardeerd.

Ing. Piet de Groot en Drs. Henk Everts (IVVO, Lelystad) dank ik voor de leerzame discussie over bepaalde gedeelten van dit onderzoek.

I would like to thank Dr. J.E. Pettigrew (University of Minnesota) and Prof. dr. E.T. Kornegay (Virginia Polytechnic Institute and State University) for critical evaluation of the manuscripts of Chapter 1 and 6, respectively.

I would like to acknowledge the Research Institute for Animal Breeding and Nutrition (Herceghalom, Hungary) and the Ministry of Agriculture (Budapest, Hungary) who allowed me to stay at the Agricultural University of Wageningen.

Bijzonder hartelijk dank aan de heer A.P.A. Monné (Ministerie van Landbouw, Natuurbeheer en Visserij, 's-Gravenhagen) voor zijn hulp en financiële steun die ons verblijf in Nederland mogelijk maakte.

De onderzoeken beschreven in de hoofdstukken 4, 5 en 6 werden deels door de firma F. Hoffmann La-Roche gefinancierd.

Auf diese Weise möchte ich mich für die Unterstützung bei der F. Hoffmann La-Roche AG (Basel) und Roche Nederland B.V. (Mijdrecht) bedanken.

Vielen Dank Dr. Dipl. Ing. Torsten Köhler für die lange Zeit, die wir in unserem Zimmer in der Abteilung für Tierernährung zusammen verbracht haben. Ich freue mich besonders darüber, daß ich mit Dir die deutsche Sprache üben konnte.

Verder wil ik het LEB-Fonds Wageningen en de firma PIC Plukovee (Barneveld) bedanken voor hun financiële steun bij de publikatie van dit proefschrift.

Dr. Barbara Williams wil ik bedanken voor de correcties van de engelse tekst van een aantal hoofdstukken.

Namens mijn vrouw en zoon wil ik langs deze weg graag dank zeggen aan alle medewerkers van de vakgroep Veevoeding voor hun vriendschapsbetuiging die ons verblijf in Wageningen zo fantastisch prettig gemaakt heeft.

Tenslotte dank ik allen die aan dit proefschrift hebben meegewerkt, maar niet met naam zijn genoemd.

Wageningen, 4 maart 1992

*László Babinszky*

# Contents

<b>GENERAL INTRODUCTION</b>	<b>1</b>
<b>CHAPTER 1 Effect of dietary fat level and vitamin E on energy- and nitrogen balances of primiparous lactating sows</b>	<b>21</b>
<b>CHAPTER 2 Metabolic rate of primiparous lactating sows and suckling piglets as affected by dietary fat level and vitamin E</b>	<b>39</b>
<b>CHAPTER 3 Effect of dietary fat level in the lactation diet on the performance of primiparous sows and their piglets</b>	<b>57</b>
<b>CHAPTER 4 Dietary vitamin E and fat source and lactating performance of primiparous sows and their piglets</b>	<b>73</b>
<b>CHAPTER 5 Effect of <math>\alpha</math>-tocopherol and dietary fat source on some blood and immunological variables in lactating sows</b>	<b>89</b>
<b>CHAPTER 6 Effect of vitamin E and fat source in sows' diets on immune response of suckling and weaned piglets</b>	<b>105</b>
<b>GENERAL DISCUSSION</b>	<b>123</b>
<b>SUMMARY</b>	<b>143</b>
<b>SAMENVATTING</b>	<b>149</b>
<b>CURRICULUM VITAE</b>	<b>155</b>
<b>MAJOR SCIENTIFIC PUBLICATIONS</b>	<b>157</b>

## **GENERAL INTRODUCTION**

## I. General

The purpose of a pig breeding herd is high productivity for minimal nutritional input. In particular, the cost of the sows' feed must be minimized. Feed costs are the major cost in pig production. To balance productivity with the production cost, it is necessary to control those aspects of reproduction which are open to manipulation by nutrition. These major aspects include the following: milk composition, milk production, body composition of sows (mobilization of fat and protein in the sow), litter size, piglet weight, survival of piglets, and, partly, the health status of animals.

The aforementioned traits are also influenced by aspects of management such as housing conditions, climatic environment, disease, and behaviour.

Numerous observations indicate that it is possible to influence the aforementioned traits by feed and/or nutrient intake. This means that sufficient feed and nutrient intake of sows play an important role in profitable pig production.

In general, the control of feed intake (voluntary feed intake) of pigs is influenced by a number of factors as summarized by NRC (1987, 1988):

- \* Physiological factors, including neural and hormonal mechanism, genetic background, olfaction and taste.
- \* Environmental factors, including environmental temperature, humidity, air movement, number of pigs per pen, available space per pig.
- \* Nutritional factors, including deficiencies or excesses of nutrients, energy density, antibiotics, flavours, feed processing and water.

These factors have to be taken into consideration for feeding strategies. According to Williams and Mullan (1989), there are two steps in the design of feeding strategies for sows. The first involves setting reproductive targets (e.g. age and weight for mating gilts, the amount of energy required during pregnancy for growth of the conceptus, the amount of energy needed to maintain milk supply during lactation yet leave the sow in an acceptable condition at weaning to commence the next reproductive cycle). The second step is setting nutrient allowances to meet these specified targets and this requires knowledge of the factors that affect the partition of nutrients between maternal tissues, the products of conception and milk.

During lactation, the sow requires nutrients to support maintenance and milk production. Milk production has a high priority and if nutrient intake is restricted, the sow will draw on body tissue in order to maintain milk production and/or support body maintenance (NRC, 1987). In other words, the milk production determines the amount of energy and protein (as the two major nutrients) which

need to be supplied in the diet. The amount of energy and protein which is not supplied by feed needs to be drawn from body reserves. This may have consequences for reproduction. These sows may have considerable weight loss associated with the negative energy balance (Drochner, 1989). A large mobilization of muscle tissue during the lactation often occurs in first-litter sows (King and Williams, 1984b) due to the fact that they may have limited body reserves to draw from. Although the sows can experience wide extremes of weight change during lactation, without any great effect on subsequent litter size (Varley and Cole, 1978; King and Williams, 1984a,b), weaning-to-mating interval may be affected, particularly in first-litter sows. Reese et al. (1982) found that energy intake during lactation is responsible for increased weaning-to-mating intervals of primiparous sows. It has also been suggested that low protein intake may contribute to extended weaning-to-mating intervals in first-litter sows (O'Grady and Hanrahan, 1975).

The total body fat in the piglet at birth represents about 1% of the carcass weight. Much of this fat is present as structural fat and is not available for mobilization (Seerley, 1984). Therefore, the nutrient and/or energy intake of piglets via colostrum and milk are very important, especially during the first week of lactation. The later performance of suckling piglets (gain, litter size, survival, health status) is dependant highly on the composition and amount of milk.

Thus there is sufficient evidence that milk production is one of the most crucial factors in sow nutrition which determines both piglets and sow performance.

The main nutritional goals during lactation are to optimize lactation weight loss and improve milk production (or milk nutrients production) and litter performance. Therefore, it is important to study the effect of dietary components on amount and composition of milk and on fat and protein mobilization in the lactating sow (energy metabolism of sows).

ARC (1981) has used the factorial approach to estimate energy requirements of lactating sows. Factors such as milk production, weight of sows, expected lactation weight loss, litter size and the length of lactation must be included in any calculation. This indicates that the dietary energy intake can play an important role in altering these traits. Because gilts consume about 15% less energy during lactation than multiparous sows (NRC, 1987), there is little chance to improve lactation energy intake by increasing daily feed consumption (in kg). The other possibility may be the increase of energy density in diets by adding fat. There are indications that fat may be beneficial for energy intake.

Fat is also an important component for vitamin E requirements. There are two major reasons. The first is that vitamin E can act as an antioxidant thus protecting unsaturated fatty acids from oxidation. Secondly, vitamin E is a fat-soluble vitamin. Fat may facilitate vitamin E intake and this may therefore influence the health status of animals and probably the performance of sows and piglets. It can be expected that there is an interaction between dietary fat and vitamin E, especially if fat

contains unsaturated fatty acids which are more likely to be oxydized during storage.

Therefore, in the present investigations, the effects of two nutrients (fat and vitamin E) were studied for the amount and composition of milk, and energy metabolism and lactation performance of primiparous sows. The effect of vitamin E on the immune system of the lactating sows and their piglets was also studied.

## **II. Role of dietary fat in sow nutrition (literature)**

Many workers have studied the effects of adding fat to the sow's diet on lactation performance as reviewed by Moser and Lewis (1980), Pettigrew (1981), and Drochner (1989). Fat supplementation of pig diets is not a novel idea. Moser and Lewis (1980) reported that Hillier in 1950 found that growing pigs can make efficient use of diets containing a high fat level. This was reflected by an improvement in daily gain and feed conversion efficiency. Similar observations were found in poultry. Many workers showed that the addition of fat to poultry diets improved feed efficiency more than expected from the increased energy density (Vermeersch and Vanschoubroek, 1968; Jensen et al., 1970). This effect has been referred to as an "extracaloric" effect of fat. A large number of studies have shown that the effects of fat addition to the sow's diet are not consistent. This can be related to different fat composition, to differences in experimental design, and to different conditions of the experiments.

### **A. Some factors affecting fat utilization**

#### ***1. Composition and digestion of dietary fat***

The major site of fat digestion in the gastro intestinal tract in the pig is the duodenum. Basically, the digestion involves emulsification of dietary fat by conjugated bile salts, followed by hydrolysis of triglycerides into mixtures consisting essentially of monoglycerides and free fatty acids (Wiseman, 1989). In pigs, saturated fatty acids alone are less absorbed than unsaturated fatty acids (Freeman et al., 1968). The micellar formation potential and absorption of saturated fatty acids is increased in the presence of unsaturated fatty acids or monoglycerides as reviewed by Stahly (1984). Therefore, the digestibility of a particular supplemental fat source in pigs is dependent on the fatty acid composition (ratio of unsaturated/saturated fatty acid) of the total diet. The digestibility of fat from diets which have a ratio of unsaturated to saturated (U/S) fatty acids greater than 1.5, is high (85-92%) compared to diets with a lower ratio (Stahly, 1984).

Pettigrew et al. (1989) concluded from their study and from literature that nursing piglets can utilize medium-chain triglycerides more efficiently than traditional fat sources rich in long-chain

triglycerides.

Moser and Lewis (1980) on the other hand, concluded from the literature data that the type of dietary fat seems to be of minor importance for the litter performance. Vegetable oil may have advantages in terms of ease of handling, but animal fats are usually less expensive (Moser and Lewis, 1980).

Drochner (1989) also concluded from different studies that the spectrum of the fatty acids is of limited importance for the efficacy.

## ***2. Dietary fat level***

The level of fat in the sow's diet may play an important role in the performance of lactating sows and suckling piglets. In most experiments, fat levels between 7.5 and 15% have been used. This range gives the best response in terms of survival of piglets according to Moser and Lewis (1980).

The results of various studies show that the increase in weaning weight is more favorable if the dietary fat concentration in sow's diet was at least 8% and was used through both late gestation and lactation periods (Pettigrew, 1981).

## ***3. Length of time of supplementation***

The length of time of fat supplementation is another variable which may influence the performance of piglets. In terms of the number of pigs weaned per litter, it seems to be more beneficial to add fat either in late gestation, or lactation rather than in both periods (Moser and Lewis, 1980). In terms of survival of piglets, the addition of fat to sow's diet during gestation alone or during gestation and lactation gave the largest response.

## ***4. Other dietary factors***

Stahly (1984) and Freeman (1984) concluded from their reviews that the digestibility of dietary fat is influenced by those dietary factors which depress the absorption of nutrients in the small intestine. This may be done by potentially altering the rate of passage of the digesta or partly insolubilizing the dietary fat. Carbohydrate sources (e.g. barley straw or potato starch) which depress the absorption of nutrients in the small intestine and stimulate fermentation in the hind gut, have been shown to depress fat digestibility in pigs (Stahly, 1984). Dietary fibre also depressed fat digestibility in the chick and laying hen (Scheele, 1981).

High levels of dietary minerals (Ca, Mg) may also depress the digestibility of long-chain fatty acids in rats. The magnitude of this relationship in pigs, however, has not been clearly defined.

## **B. Dietary fat and lactation performance**

### **1. Live weight of sows and piglets**

Cox et al. (1983) reported that sows fed a control diet (no additional fat) or 10% fat supplemented diets ad libitum, lost weight during lactation on both diets. During the summer period no differences between the control and treatment groups were found. However, in the winter trial, sows fed the fat-supplemented diet lost more weight than control animals, probably due to less heat increment. Schoenherr et al. (1989) found that weight change in the sow during a 22-day lactation period was not affected by diets containing starch or fat in either a thermoneutral (20 °C) or a hot (32 °C) environment, when sows were fed ad libitum.

Seerley et al. (1981) reported that sows fed a diet ad libitum without fat supplementation did not consume extra feed or had a different weight loss compared to sows with 10% added corn oil or 10% added animal fat in their diet. Control animals, which showed greater weight loss, generally had a lower energy intake. Nelssen et al. (1985) found that sows fed at a restricted level with a tallow-supplemented diet from gestation throughout lactation lost more weight during lactation, than animals fed a diet with cornstarch. They concluded that the short adaptation period (6 days) to the diet containing animal fat may have resulted in poor digestion of animal fat. Restricted energy intake during lactation, lower digestion of dietary fat and higher energy content in the milk may result in extra weight loss of sows.

Data from the literature show that, overall, dietary fat had only minor or no effect on the piglet weight at either birth or weaning (Moser and Lewis, 1980). Pettigrew (1981) reviewed 16 trials (no creep feed during suckling) in which 9 trials showed a positive effect on the weaning weight of piglets when fat was added to sow's diet and 7 trials showed nothing or a small negative effect. He concluded that the mean piglet weight at weaning appears to increase if the dietary fat concentration is at least 8%. Coffey et al. (1982) and Nelssen et al. (1985) reported no significant differences in average piglet weight during the suckling period if the sow's diet was supplemented with fat.

Many studies were conducted to determine the dietary fat effect on weight change of sows and their piglets, but the results are inconsistent. The results of experiments indicate that supplemental fat during lactation may provide two benefits, a reduction in the weight loss of the sows, and an increased weaning weight of the litter. However, both responses are not large and may not justify the cost of the fat (Pettigrew, 1989).

### **2. Survival of piglets**

Pre-weaning mortality is a major source of animal losses. During the suckling period the mortality of piglets is approximately 14 % (Baltussen, 1988). Many pre-weaning piglet deaths may

result from a shortage of energy (Pettigrew, 1989). Addition of fat to the sow's diet during late gestation, in that case, might increase the fat content of the colostrum and milk, and this will increase the total amount of energy transferred to the piglets via the mammary glands of sow (Pettigrew, 1989). Reviews on the subject (Moser and Lewis, 1980; Pettigrew, 1981; Seerley, 1981; Drochner 1989) suggest that this increased transfer of energy to the piglets may improve their survival rate. Most of the studies from the gestation group showed improvement in piglet survival rate. However, when fat was added after farrowing, little effect was observed (Seerley, 1984).

It should be noted that when pre-weaning survival is at an acceptable level, it is not improved by additional fat. With low pre-weaning survival, however, supplemental fat can be beneficial but there are probably more effective means of improving it (Pettigrew, 1989). Drochner (1989) also concluded from the literature data, that the positive effect of dietary fat for survival is predominant, when birth weights are low and when there are large litters and low survival rates.

### **3. Milk composition**

The effect of dietary fat on the composition of milk, (particularly the fat content) has been widely investigated. Fatty acids in the milk are derived from two sources: firstly from the blood lipids which include both endogenous and dietary fatty acids. Secondly, it may be derived from de novo synthesis in the mammary glands (Hartmann and Holmes, 1989). This means that the concentration of fat in colostrum and milk can be increased by increasing the fat level in the sow's diet, as has been found in numerous studies (Miller et al., 1971; Friend, 1974, Seerley et al., 1974, 1978a,b; Boyd et al., 1978; Coffey et al., 1982, Pettigrew, 1981; Drochner, 1989).

Contents of protein, lactose, and total solids, were not affected by the fat level in the sow's diet according to Coffey et al. (1982) and Drochner (1989).

### **4. Milk production**

The effect of dietary fat on the milk yield of sows in various studies, are given in Table 1. The data demonstrate that the comparison of results between different studies is difficult because the daily feed and/or ME intake of sows during lactation was not always controlled. Also, different measuring techniques for estimation of milk yield (weigh-suckle-weigh method, D<sub>2</sub>O dilution technique, regression equation relating pig weight gain) were used. These may influence the magnitude of milk production. Furthermore, in most studies multiparous sows were used or there is no information about the effects of parity.

Generally, it may be concluded from the literature data that fat addition to the sow's lactation diet may only have a slightly positive effect on the milk production of sows, or no effect at all.

**Table 1. Effect of supplemental dietary fat on milk production of sows in various studies**

Reference	Fat in diet	Feeding during lactation	Fat effect on feed or ME intake	Fat effect on milk yield
Pettigrew (1981) <sup>a</sup>	animal fat or corn oil	no data	no data	slightly increased
Boyd et al. (1982) <sup>b</sup>	tallow	ad libitum	isocaloric	slightly increased
Coffey et al. (1982) <sup>b</sup>	animal fat	rationed	isocaloric	positive
Lellis and Speer (1983) <sup>b</sup>	tallow	rationed	isocaloric	no effect
Shurson et al. (1986) <sup>b</sup>	animal fat	ad libitum	increased	positive
Schoenherr et al. (1987) <sup>b</sup>	choice white grease	ad libitum	increased	no effect

<sup>a</sup> Review and own results.

<sup>b</sup> Own experimental results.

### C. Energy metabolism and fat

The effect of dietary fat on energy metabolism of lactating sows has not been studied intensively. Most investigations used rats, growing pigs, non-pregnant non-lactating sows or other species. The most important question for fat nutrition during lactation is whether the extra dietary fat can influence the energy balance, heat production, or an alteration in body composition (mobilization of fat and protein in sow). If so, fat might be used to manipulate the metabolism of sows. Another important question is whether it is possible, in a well controlled experiment to improve the efficiency of milk production from metabolizable energy of feed (ME) above maintenance with a high level of dietary fat.

Nutrients are required by animals both as an energy source and as materials for the construction of body tissues and the synthesis of milk and eggs. This production requires energy above that required for maintenance. Energy supplied by feed in excess of that needed for maintenance is used for the various forms of production. A young growing animal will store energy in the form of protein in its new tissues at a greater rate than a mature animal. The latter will store relatively more energy as fat and a lactating animal will transfer feed energy into the energy in milk constituents (McDonald et al., 1988). However, it also must be pointed out that piglets store more energy as fat than as protein (Whittemore et al., 1978).

The ingestion of feed by animals is followed by losses of energy, not only as the chemical energy in its solid, liquid and gaseous excreta, but also as heat. Heat is produced as a result of the many metabolic processes occurring within the animal. The extent to which it occurs is not only characteristic of the animal per se, but is dependent upon nutritional, productive, environmental and other related factors (Close and Verstegen, 1981). This may indicate that the dietary nutrients such as fat and carbohydrates may also influence energy metabolism and particularly the thermogenesis of animals.

The relative energetic value of fat and carbohydrates for body metabolism depends on the use of that energy source for maintenance or for tissue synthesis (Chudy and Schiemann, 1969; Nehring and Haenlein, 1973). A study with growing rats indicated that dietary fat calories appear to be preferentially utilized for body-fat synthesis rather than for other purposes (Chudy and Schiemann, 1969). The greater efficiency of utilizing fat calories for fatty tissue synthesis is because dietary fat can be directly incorporated into body fat, which minimizes the heat losses normally associated with fat synthesis from acetyl CoA (Stahly, 1984). This suggests that absorbed dietary fatty acids may be preferentially used for the formation of body fat if sufficient alternative energy sources are present in a ratio to meet all other energy requirements. It would be expected that the efficiency of utilization of ME would increase as the proportion of that energy derived from dietary fat increased, until the capacity of the animal for lipogenesis is exceeded (Hillcoat and Annison, 1974). The effect of dietary fat on efficiency thus depends on the feeding level and on how much fat deposition from the diet occurs.

The results of heat production and energy balances have shown that the response to dietary fat is variable. Müller and Kirchgessner (1980) found no differences in heat production and in energy retention in mature, non-pregnant sows fed a diet containing only protein and fat or a mixed diet (protein and carbohydrate plus fat). Kirchgessner and Müller (1984) reported that, in non-pregnant, non-lactating, mature sows, a high-fat diet fed at approximately maintenance level had no diet-induced thermogenesis compared to a carbohydrate-rich diet. Prabucki and Schürch (1977) also found that, in rats fed at a low level of intake, the ratio of carbohydrates to fat in isocaloric diets had no effect on heat production.

Hillcoat and Annison (1974), on the other hand, noted that with growing pigs heat production tended to decrease with increasing dietary fat level. It should be noted, however, that the daily level of ME intake of their animals was higher compared to some other studies. In most other studies, animals were fed at approximately maintenance level, and this explains why, in most cases, no effects were found. It is relevant therefore, to measure the effects of fat addition to the diet on energy metabolism in animals which have a high feeding level e.g. lactating sows.

### III. Role of dietary vitamin E in sow nutrition (literature)

#### A. General

##### 1. Name, chemical forms and absorption of vitamin E

Vitamin E is the name given to a group of 8 chemicals called tocopherols (Mackinnon, 1989). The multiple nature of vitamin E became evident in 1936 when Evans and his co-workers (after Ullrey, 1981) isolated two compounds with vitamin E activity from wheat germ oil. These were named  $\alpha$ - and  $\beta$ -tocopherol. Subsequent investigations isolated  $\gamma$ - and  $\delta$ -tocopherols and disclosed the existence of four tocotrienols in several vegetable oils (Ullrey, 1981). The most biologically active form is  $\alpha$ -tocopherol. A synthetic form,  $\alpha$ -tocopheryl acetate, is used to supplement naturally-occurring tocopherols in feedstuffs. There are two forms of  $\alpha$ -tocopheryl acetate, the "d" and "l" isomers (sometimes also "D" and "L" are used depending on the editorial policy). The d-isomer is more active than the l-isomer (Mackinnon, 1989). Because  $\alpha$ -tocopherol has the highest vitamin E activity, it is common to assay this isomer only rather than to perform the more difficult separation and quantification of all eight natural compounds (Ullrey, 1981).

The concentration of vitamin E-active compounds is low in animal tissues and occur as a consequence of the consumption of tocols and tocotrienols in plants or commercially produced tocopherols fed as dietary supplements.

Absorption of vitamin E is related to fat digestion and is facilitated by bile and pancreatic lipase (Wiss et al., 1962, after Ullrey, 1981).

##### 2. Vitamin E supplementation to sow diets

The recommendation for supplementation of vitamin E to sow diets varies considerably among different countries (Table 2.). In Denmark, the dietary supplemental level of vitamin E is 37 IU/kg diet, while in many other countries the levels used are much lower. In the Netherlands, the level of vitamin E used is 9 IU/kg diet. Within a country sow diets can vary from 10 to 30 IU/kg diet (Klaver and den Hartog, 1983).

**Table 2. Recommended levels of supplementation of vitamin E in sow diets (IU/kg) in several countries (Klaver and den Hartog, 1983)**

	U.K. (ARC,1981)	Canada/US (NRC,1988)	Nether- lands	Germany (DLG,1982)	France (AEC,1988)	Denmark
Vitamin E (IU/kg)	9	10	9	20	14	37

IU= international unit= 1 mg  $\alpha$ -tocopheryl acetate.

### **3. Vitamin E ( $\alpha$ -tocopherol) concentration in blood, colostrum and milk**

Several papers have demonstrated that plasma and serum vitamin E ( $\alpha$ -tocopherol) concentration in sows, may be influenced by dietary vitamin E level (Young et al., 1977; Loudenslager et al., 1986). Drochner (1976) concluded from different studies that  $\alpha$ -tocopherol concentration in the serum is in equilibrium with dietary vitamin E. Therefore, the serum  $\alpha$ -tocopherol concentration is not a good parameter for estimation of the tocopherol status of the animal, but it can be a good indicator for vitamin E content of the diet.

Prior to suckling,  $\alpha$ -tocopherol concentration in the serum of the newborn piglets is low. The low plasma and tissue levels of  $\alpha$ -tocopherol in the neonatal pigs suggest that there is a low rate of vitamin E transfer across the placenta (Pharazyn et al., 1990).

During suckling, colostrum represents the major source of vitamin E for the neonate, providing an accumulation of tissue reserves of  $\alpha$ -tocopherol seen in the first week of life (Dvorak, 1979). Cline et al. (1974), Young et al. (1977) and Loudenslager et al. (1986) found that  $\alpha$ -tocopherol content of sow colostrum and milk was increased with added vitamin E in the diet. Malm et al. (1976) reported that animal fat from lard tended to promote a higher concentration of  $\alpha$ -tocopherol in milk fat than corn oil did (Table 3.).

Results of these studies indicate that  $\alpha$ -tocopherol concentration in colostrum and in milk can be enhanced by a higher level of dietary vitamin E.

### **4. Factors influencing the vitamin E needs of swine**

Many factors may influence the vitamin E needs of swine. Adams and Zimmerman (1982) have published a survey of various dietary factors such as content, bioavailability and stability of vitamin E, content of selenium in the diets, and animal factors (e.g. performance). It has also been stated in many reports that increasing the fat content of the diet, particularly the polyunsaturated fatty acid (PUFA) content, increases the requirement for  $\alpha$ -tocopherol (Pharazyn et al., 1990).

## **B. Main functions of vitamin E in animals**

In various investigations it has been reported that vitamin E may play a role in improving the reproductive performance of sows. It appears to function as an intracellular antioxidant (Putnam, 1982). It also may influence the architecture of membrane phospholipids, inhibit the aggregation of blood platelets, and improve the immune status and the response to infection (Ullrey, 1981).

**Table 3. Influence of vitamin E and polyunsaturated fat level in gestation diets on  $\alpha$ -tocopherol in colostrum and milk (taken from Malm et al., 1976)**

Diet	Low vit.E lard	High vit.E lard	Low vit.E corn oil	High vit.E corn oil
$\alpha$ -tocopherol ( $\mu$ g/g fat)				
Colostrum	24 <sup>a</sup> (3) <sup>1</sup> (15-34) <sup>2</sup>	212 <sup>a</sup> (4) (184-251)	14 <sup>a</sup> (2) (7-21)	90 <sup>b</sup> (2) (51-130)
Milk at three weeks	4 <sup>a</sup> (1)	43 <sup>b</sup> (4) (32-58)	1 <sup>a</sup> (1)	35 <sup>b</sup> (3) (27-44)

<sup>1</sup> No. of samples in parentheses.

<sup>2</sup> Range.

<sup>a,b</sup> Data within a row with different superscripts are significantly different from each other ( $P < 0.05$ ).

### 1. *In vivo antioxidant, blood clotting, prostaglandins synthesis*

The cell membrane contain various fats or lipids, many of which are unsaturated. This means that, unlike saturated fats, they do not contain their full complement of hydrogen atoms. Therefore, they are "open" to take up certain elements, particularly oxygen. Oxidation of lipids describes the process by which fats become rancid. Without vitamin E, body lipids undergo a similar process (Mackinnon, 1989).

The antioxidant properties of vitamin E also help to maintain the structure and function of red blood cells, blood vessels, the nervous system and the endocrine and hormonal system. As reviewed by Ullrey (1981), it appears that vitamin E is an inhibitor of platelet aggregation. The increase in lipid peroxides normally associated with platelet aggregation is reduced by vitamin E.

Vitamin E also may modulate synthesis of prostaglandins, which are important regulators of immune responses. Since increased prostaglandin concentrations may be immunosuppressive, the ability of vitamin E to prevent infection-induced increases in prostaglandins may also contribute to the enhancing effects of vitamin E on the immune response (Sheffy and Schultz, 1979; Likoff et al., 1981).

### 2. *Immunity*

The effect of vitamin E on the immune system of animals has been reviewed by Ullrey (1981); Nockels (1983, 1986) and Pharazyn et al. (1990). How vitamin E influences the immune system of animals is not clearly understood. Vitamin E seems to exert its enhancing effect on the immune response by stimulating ubiquinone synthesis and this compound increases phagocytic activity

(reviewed by Herlyn and Glaser, 1976). Tocopherols do indeed stimulate phagocytosis, however, exceeding the dose results in the opposite effect (Gropp and Birzer, 1989).

Some studies have demonstrated that vitamin E can improve humoral and cell-mediated immunity of animals.

Studies with chickens have shown that vitamin E enhances resistance to bacterial infection and also the humoral immune response to antigenic stimulation (Tengerdy et al., 1972; Tengerdy and Nockles, 1975; Tengerdy and Brown, 1977). Protection from bacterial infection was correlated with increased phagocytosis and increased antibody production (Tengerdy and Brown, 1977).

Hayek et al. (1989) reported that a single i.m. injection of vitamin E and/or selenium into the sows on day 100 of pregnancy subsequently increased IgG concentration in piglet serum on day 14 of suckling.

Tanaka et al. (1979) found that vitamin E stimulated the helper activity of T-lymphocytes in mice. In 7 to 10-week-old mice after injection of vitamin E (Yasunaga et al., 1982) and in weanling rats fed a vitamin E supplemented diets (Bendich et al., 1986), the increased lymphocyte mitogenic response indicated that vitamin E could influence cellular immunity. Other studies with weaned piglets, however, did not indicate an effect of dietary vitamin E on humoral and cell-mediated immune response (Kornegay, 1986; Bonnette et al., 1990a,b).

Data from literature show that the effect of vitamin E on the immune response of animals is not consistent and only scarce information is available on lactating sows and suckling piglets. In most studies chickens, rats, mice, weaned piglets, or other species were used.

### ***3. Reproductive performance and milk production of sow***

Several investigations have concluded that vitamin E can influence reproductive performance of sows. This effect is more pronounced in older sows than in gilts (Adams and Zimmerman, 1982; Chavez and Patton, 1986; Mahan, 1991). Results in a few trials indicate that after the second and third farrowing, sows fed supplemental vitamin E had more live piglets born per litter and heavier piglet weight at three weeks of lactation compared to the unsupplemented sows.

Malm et al. (1976) found no significant effect of high vitamin E supply on reproductive performance (number and weight of piglets) of 7 to 8 month-old sows fed with sunflower oil or animal fat. Nielsen et al. (1979) also reported that higher levels of selenium and vitamin E (45 mg/kg diet) in the sow's diet had no significant effect on litter size nor on piglets' weight. Adams and Zimmerman (1982) reported, that multiparous sows fed supplemental vitamin E had increased milk production compared with unsupplemented sows. Nielsen et al. (1979) also found a tendency to an increase in milk yield of the sows following additions of selenium and vitamin E to the diet. In an earlier study, Nielsen et

al. (1973) observed a dramatic drop in milk production for sows on low vitamin E diets.

#### **IV. Conclusions from literature and scope of present thesis**

From the literature it can be concluded that the effect of fat addition to the sow's diet on practical traits has been studied quite extensively. Data have shown that the fat concentration in colostrum and milk is increased with higher dietary fat levels in the sow's diet. Although most of the studies suggested an increase in weaning weight with extra fat in the diet, the increases were small and usually not statistically significant. Adding fat to sow diets can improve pig survival. However, the improvement is small, and has not been observed in all experiments. Data from different studies have shown also that the fat supplementation had no clear effect on the weight change and milk production of sows.

There is only limited information on the energy metabolism of lactating sows (energy balance, heat production, protein and fat mobilization) fed different levels of dietary fat. Data available mostly relate to non-lactating animals and are somewhat inconsistent.

Results from different trials have shown that dietary vitamin E can increase the  $\alpha$ -tocopherol concentration in serum, colostrum and milk. In the literature, studies with chickens, rats, mice, and with weaned and growing pigs, indicate that vitamin E may influence the immune system of these animals. However, the systematic studies on the effects of vitamin E on the immune response in lactating sows and suckling piglets are very limited and the results are not consistent. Results showed only minor positive vitamin E effects on reproduction performance and on milk production.

Data of literature show that the parity may determine the effect of fat and vitamin E. Because multiparous sows may have a more variable history between animals it was arbitrarily decided to focus on primiparous sows. Moreover, primiparous sows have a lower feed intake and so fat may have a larger effect on their energy balance traits than in older sows.

Fat probably stimulates the energy output in milk. This will undoubtedly have an effect on energy metabolism. Vitamin E may have an effect on fat uptake from the gastrointestinal tract especially at high levels of unsaturated fat. This has not been investigated until now. Therefore, we decided to study the interaction of dietary fat and vitamin E with regard to energy metabolism.

The present thesis therefore, focuses on the following questions:

1. What is the effect of different levels of dietary fat and vitamin E in the lactation diet on:
  - \* the energy metabolism of primiparous lactating sows (Chapter 1 and 2);
  - \* the lactating performance of primiparous sows and their piglets (Chapter 3 and 4);
  - \* the composition of milk (Chapter 3 and 4);
  - \* the milk production and efficiency of milk production of primiparous sows (Chapter 1, 3 and 4);
2. What is the effect of different levels of dietary vitamin E and different types of dietary fat in the sow's diet on:
  - \* the lactation performance of primiparous sows and their piglets (Chapter 4);
  - \* the immune response of primiparous sows and their piglets (Chapter 5 and 6).

In the present thesis both vitamin E and  $\alpha$ -tocopherol are used interchangeably i.e. vitamin E. In various chapters which have been submitted to different journals, one or the other is used depending on the requirement of the journal. Both names refer to the same compound, however.

## References

- Adams, C.R. and C.R. Zimmerman. 1982. Many factors affect pigs' vitamin E needs. *Feedstuffs* 24: 30-31.
- ARC. 1981. The Nutrient Requirements of Pigs. Commonwealth Agricultural Bureaux, Farnham Royal, Slough.
- Baltussen, W.H.M. 1988. Verschillen tussen praktijkbedrijven in voeding van zeugen en biggen. Proefstation voor de Varkenshouderij, Landbouw Economisch Instituut, Rosmalen. Proefverslag nummer P 1.28. pp. 29.
- Bendich, A., E. Gabriel and L.J. Machlin. 1986. Dietary vitamin E requirement for optimum immune responses in the rat. *J. Nutr.* 116: 675-681.
- Bonnette, E.D., E.T. Kornegay, M.D. Lindemann and C. Hammerberg. 1990a. Humoral and cell-mediated immune response and performance of weaned pigs fed four supplemental vitamin E levels and housed at two nursery temperatures. *J. Anim. Sci.* 68: 1337-1345.
- Bonnette, E.D., E.T. Kornegay, M.D. Lindemann and D.R. Notter. 1990b. Influence of two supplemental vitamin E levels and weaning age on performance, humoral antibody production and serum cortisol levels of pigs. *J. Anim. Sci.* 68: 1346-1353.
- Boyd, R.D., B.D. Moser, E.R. Peo, Jr. and P.J. Cunningham. 1978. Effect of energy source prior to parturition and during lactation on piglet survival and growth and on milk lipids. *J. Anim. Sci.* 47: 883-892.
- Boyd, R.D., B.D. Moser, E.R. Peo, Jr., A.J. Lewis and R.K. Johnson. 1982. Effect of tallow and choline chloride addition to the diet of sows on milk composition, milk yield and preweaning pig performance. *J. Anim. Sci.* 54: 1-7.
- Chavez, E.R. and K.L. Patton. 1986. Response to injectable selenium and vitamin E on reproductive performance of sows receiving a standard commercial diet. *Can. J. Anim. Sci.* 66: 1065-1074.
- Chudy, A. and R. Schiemann. 1969. Utilization of dietary fat for maintenance and fat deposition in model studies with rats. In: K.L. Blaxter, J. Kielanowski and G. Thorbeck (Eds) *Energy Metabolism of Farm Animals*. pp. 161-168. EAAP Publications. Publication No. 12. Oriel Press, England.
- Cline, J.H., D.C. Mahan and A.L. Moxon. 1974. Progeny effects of supplemental vitamin E in sow diets. *J. Anim. Sci.* 39: 974 (Abstract).
- Close, W.H. and M.W.A. Verstegen. 1981. Factors influencing thermal losses in non-ruminants: a review. *Livest. Prod. Sci.* 8: 449-463.
- Coffey, M.T., R.W. Seerley and J.W. Mabry. 1982. The effect of source of supplemental dietary energy on sow milk yield, milk composition and litter performance. *J. Anim. Sci.* 55: 1388-1394.
- Cox, N.M., J.H. Britt, W.D. Armstrong and H.D. Alhusen. 1983. Effect of feeding fat and altering weaning schedule on rebreeding in primiparous sows. *J. Anim. Sci.* 56: 21-29.
- Drochner, W. 1976. Aktuelle Ergebnisse der Vitamin-E-Forschung, dargestellt am Beispiel der Vitamin-E-Versorgung des Schweines [in German]. *Übers. Tierernähr.* 4: 93-131.
- Drochner, W. 1989. Einflüsse von Fettzulagen an Sauen auf Aufzuchtleistung und Fruchtbarkeit [in German]. *Übers. Tierernähr.* 17: 99-138.
- Dvorak, M. 1979. Interaction between adrenocortical activity and vitamin E level with regard to the development of myopathy in pigs. *Acta Agric. Scand.* suppl.21: 490-494.
- Freeman, C.P. 1984. The digestion, absorption and transport of fats. Non-ruminants. In: J. Wiseman (Ed) *Fats in Animal Nutrition*. pp. 105-122. Butterworths, London.
- Freeman, C.P., D.W. Holme and E.F. Annison. 1968. The determination of the true digestibilities of interesterified fats in young pigs. *Br. J. Nutr.* 22: 651-660.
- Friend, D.W. 1974. Effect on the performance of pigs from birth to market weight of adding fat to the lactation diet of their dams. *J. Anim. Sci.* 39: 1073-1081.
- Gropp, J. and D. Birzer. 1989. Nutritive, nicht mikrobiell bedingte Immunsuppression [in German]. *Übers. Tierernähr.* 17: 85-98.

- Hartmann, P.E. and M.A. Holmes. 1989. Sow lactation. In: J.L. Barnett and D.P. Hennessy (Eds) *Manipulating Pig Production II*. pp. 72-97. Australasian Pig Science Association. Werribee, Victoria, Australia.
- Hayek, M.G., G.E. Mitchell, Jr., R.J. Harmon, T.S. Stahly, G.L. Cromwell, R.E. Tucker and K.B. Barker. 1989. Porcine immunoglobulin transfer after parturition treatment with selenium or vitamin E. *J. Anim. Sci.* **67**: 1299-1306.
- Herlyn, D. and H. Glaser. 1976. Vitaminversorgung und Immunantwort [in German]. *Übers. Tierernähr.* **4**: 235-261.
- Hillocoat, J.B. and E.F. Anison. 1974. The efficiency of utilization of diets containing maize oil, tallow and tallow acid oil in the pig. In: K.H. Menke, H.J. Lantzsch and J.R. Reichl (Eds) *Energy Metabolism of Farm Animals*. pp. 177-180. EAAP Publications. Publication No. 14. Universität Hohenheim, Germany.
- Jensen, L.S., G.W. Schumaier and J.D. Latshaw. 1970. "Extra caloric" effect of dietary fat for developing turkeys as influenced by calorie-protein ratio. *Poul. Sci.* **49**: 1697-1704.
- King, R.H. and I.H. Williams. 1984a. The effect of nutrition on the reproductive performance of first-litter sows. 1. Feeding level during lactation, and between weaning and mating. *Anim. Prod.* **38**: 241-247.
- King, R.H. and I.H. Williams. 1984b. The effect of nutrition on the reproductive performance of first-litter sows. 2. Protein and energy intakes during lactation. *Anim. Prod.* **38**: 249-256.
- Kirchgessner, M. and H.L. Müller. 1984. Thermogenese bei Verabreichung einer ketogenen Diät im Modellversuch an Sauen [in German]. *Int. J. Vitam. Nutr. Res.* **54**: 99-106.
- Klaver, J. and L.A. den Hartog. 1983. Vitamines in de zeugenvoeding. *Bedrijfsontwikkeling* [in Dutch]. **14**: 383-386.
- Kornegay, E.T., J.B. Meldrum, G. Schurig, M.D. Lindemann and F.C. Gwazdauskas. 1986. Lack of influence of nursery temperature on the response of weaning pigs to supplemental vitamins C and E. *J. Anim. Sci.* **63**: 484-491.
- Lellis, W.A. and V.C. Speer. 1983. Nutrient balance of lactating sows fed supplemental tallow. *J. Anim. Sci.* **56**: 1334-1339.
- Likoff, R.O., D.R. Guptill, L.M. Lawrence, C.C. McKay, M.M. Mathias, C.F. Nockels and R.P. Tengerdy. 1981. Vitamin E and aspirin depress prostaglandins in protection of chickens against *Escherichia coli* infection. *Am. J. Clin. Nutr.* **34**: 245-251.
- Loudenslager, M.J., P.K. Ku, P.A. Whetter, D.E. Ullrey, C.K. Whitehair, H.D. Stowe and E.R. Miller. 1986. Importance of diet of dam and colostrum to the biological antioxidant status and parenteral iron tolerance of the pig. *J. Anim. Sci.* **63**: 1905-1914.
- Mackinnon, J. 1989. Strategies on vitamin E. *Pig Intern.* **3**: 12-17.
- Mahan, D.C. 1991. Assessment of the influence of dietary vitamin E on sows and offspring in three parities: reproductive performance, tissue tocopherol, and effects on progeny. *J. Anim. Sci.* **69**: 2904-2917.
- Malm, A., W.G. Pond, E.F. Walker, Jr., M. Homan, A. Aydin and D. Kirtland. 1976. Effect of polyunsaturated fatty acids and vitamin E level of the sow gestation diet on reproductive performance and on level of alpha tocopherol in colostrum, milk and dam and progeny blood serum. *J. Anim. Sci.* **42**: 393-399.
- McDonald, P., R.A. Edwards, J.F.D. Greenhalgh. 1988. Evaluation of foods. In: P. McDonald, R.A. Edwards and J.F.D. Greenhalgh (Eds) *Animal Nutrition*. pp. 217-243. Longman Scientific & Technical, Essex.
- Miller, G.M., J.H. Conrad and R.B. Harrington. 1971. Effect of dietary unsaturated fatty acids and stage of lactation on milk composition and adipose tissue in swine. *J. Anim. Sci.* **32**: 79-83.
- Moser, B.D. and A.J. Lewis. 1980. Adding fat to sow diets. An update. *Feedstuffs* **52**: 36-62.
- Müller, H.L. and M. Kirchgessner. 1980. Energy utilization of a carbohydrate-free protein-fat diet by sows. In: L.E. Mount (Ed) *Energy Metabolism*. pp. 249-252. EAAP Publications. Publication No. 26. Butterworths, London.

- Nehring, K. and G.F.W. Haenlein. 1973. Feed evaluation and ration calculation based on net energy. *J. Anim. Sci.* 36: 949-964.
- Nelssen, J.L., A.J. Lewis, E.R. Peo, Jr. and B.D. Moser. 1985. Effect of source of dietary energy and energy restriction during lactation on sow and litter performance. *J. Anim. Sci.* 60: 171-178.
- Nielsen, H.E., V. Danielsen, M.G. Simesen, G. Gissel-Nielsen, W. Hjarde, T. Leth and A. Basse. 1979. Selenium and vitamin E deficiency in Pigs. I. Influence on growth and reproduction. *Act. Vet. Scand.* 20: 276-288.
- Nielsen, H.E., N.J. Højgaard-Olsen, W. Hjarde and E. Leerbeck. 1973. Vitamin E content in colostrum and sows milk and sow milk yield at two levels of dietary fats. *Acta Agric. Scand. Suppl.* 19: 35-38.
- Nockels, C.F. 1983. Vitamin E increases disease resistance. *Pig News and Inform.* 4: 289-291.
- Nockels, C.F. 1986. Nutrient modulation of the immune system. In: W. Haresign and D.J.A. Cole (Eds) *Recent Advances in Animal Nutrition*. pp. 177-192. Butterworths, London.
- NRC. 1987. Predicting Feed Intake of Food-Producing Animals. 3. Swine. pp. 25-41. National Research Council. Washington D.C.
- NRC. 1988. Nutrient Requirements of Swine. National Research Council. Washington D.C.
- O'Grady, J.F. and T.J. Hanrahan. 1975. Influence of protein level and amino-acid supplementation of diets fed in lactation on the performance of sows and their litters. 1. Sow and litter performance. *Ir. J. Agric. Res.* 14: 127-135.
- Pettigrew, J.E., Jr. 1981. Supplemental dietary fat for periparturient sows: a review. *J. Anim. Sci.* 53: 107-117.
- Pettigrew, J.E., Jr., M.D. Tokach, M. Overland and R.L. Moser. 1989. Use of supplemental fat in swine diets explored. *Feedstuffs* 61: 18-28.
- Pharazyn, A., L.A. den Hartog and F.X. Aherne. 1990. Vitamin E and its role in the nutrition of the gilt and sow: a review. *Livest. Prod. Sci.* 24: 1-13.
- Prabucki, A.L. and A. Schürch. 1977. The heat production of rats fed isocaloric and protein-equivalent diets with different proportions of fat to carbohydrates. *Bibl. Nutr. Dieta (Basle)* 25: 78-82.
- Putnam, M.E. 1982. Vitamin E for pigs. *Pigs Vet. Soc. Proc.* 9: 178-183.
- Reese, D.E., B.D. Moser, E.R. Peo, Jr., A.J. Lewis, D.R. Zimmerman, J.E. Kinder and W.W. Stroup. 1982. Influence of energy intake during lactation on the interval from weaning to first estrus in sows. *J. Anim. Sci.* 55: 590-598.
- Scheele, C.W. 1981. Mengvoerder samenstelling en mengvoerder benutting [in Dutch]. *Plumveehouderij* 36: 20-21.
- Schoenherr, W.D., T.S. Stahly and G.L. Cromwell. 1987. The effects of dietary fat and fiber addition on yield and composition of milk from sows housed in a warm or hot environment. *J. Anim. Sci.* 65: 318. (Abstract).
- Schoenherr, W.D., T.S. Stahly and G.L. Cromwell. 1989. The effects of dietary fat or fiber addition on yield and composition of milk from sows housed in a warm or hot environment. *J. Anim. Sci.* 67: 482-495.
- Seerley, R.W. 1981. High fat rations for sows can benefit piglets. *Feedstuffs* 53: 34-41.
- Seerley, R.W. 1984. The use of fat in sow diets. In: J. Wiseman (Ed) *Fats in Animal Nutrition*. pp. 333-352. Butterworths, London.
- Seerley, R.W., F.M. Griffin and H.C. McCampbell. 1978a. Effect of sow's dietary energy source on sow's milk and piglet carcass composition. *J. Anim. Sci.* 46: 1009-1017.
- Seerley, R.W., J.S. Maxwell and H.C. McCampbell. 1978b. A comparison of energy sources for sows and subsequent effect on piglets. *J. Anim. Sci.* 47: 1114-1120.
- Seerley, R.W., T.A. Pace, C.W. Foley and R.D. Scarth. 1974. Effect of energy intake prior to parturition on milk lipids and survival rate, thermostability and carcass composition of piglets. *J. Anim. Sci.* 38: 64-70.
- Seerley, R.W., R.A. Snyder and H.C. McCampbell. 1981. The influence of sow dietary lipids and

- choline on piglet survival, milk and carcass composition. *J. Anim. Sci.* **52**: 542-550.
- Sheffy, B.E. and R.D. Schultz. 1979. Influence of vitamin E and selenium on immune response mechanisms. *Fed. Proc.* **38**: 2139-2143.
- Shurson, G.C., M.G. Hogberg, N. DeFever, S.V. Radecki and E.R. Miller. 1986. Effects of adding fat to the sow lactation diet on lactation and rebreeding performance. *J. Anim. Sci.* **62**: 672-680.
- Stahly, T.S. 1984. Use of fats in diets for growing pigs. In: J. Wiseman (Ed) *Fats in Animal Nutrition*. pp. 313-331. Butterworths, London.
- Tanaka, J., H. Fujiwara and M. Torisu. 1979. Vitamin E and immune response. I. Enhancement of helper T cell activity by dietary supplementation of vitamin E in mice. *Immunology* **38**: 727-734.
- Tengerdy, R.P. and J.C. Brown. 1977. Effect of vitamin E and A on humoral immunity and phagocytosis in *E. coli* infected chicken. *Poul. Sci.* **56**: 957-963.
- Tengerdy, R.P., R.H. Heinzerling and C.F. Nockels. 1972. Effect of vitamin E on the immune response of hypoxic and normal chickens. *Infct. Immun.* **5**: 987-989.
- Tengerdy, R.P. and C.F. Nockels. 1975. Vitamin E or vitamin A protects chickens against *E. coli* infection. *Poul. Sci.* **54**: 1292-1296.
- Ullrey, D.E. 1981. Vitamin E for swine. *J. Anim. Sci.* **53**: 1039-1056.
- Varley, M.A. and D.J.A. Cole. 1978. The relationship between the weight change of the sow and her reproductive output. *Anim. Prod.* **26**: 368.(Abstarct).
- Vermeersch, G. and F. Vanschoubroek. 1968. The quantification of the effect of increasing levels of various fats on body weight gain, efficiency of food conversion and food intake of growing chicks. *Brit. Poul. Sci.* **9**: 13-30.
- Whittemore, C.T., A. Aumaitre and I.H. Williams. 1978. Growth of body components in young weaned pigs. *J. Agric. Sci. Camb.* **91**: 681-692.
- Williams, I.H. and B.P. Mullan. 1989. Nutritional influences on sows. In: J.L. Barnett and D.P. Hennessy (Eds) *Manipulating Pig Production II*. pp. 285-289. Australasian Pig Science Association, Werribee, Victoria, Australia.
- Wiseman, J. 1989. Fatty acids in pig nutrition. In: *Fatty Acids in Animal Nutrition*. Proc. Am. Soybean Ass. 41-56.
- Yasunaga, T., H. Kato, K. Ohgaki, T. Inamoto and Y. Hikasa. 1982. Effect of vitamin E as an immunopotentiating agent for mice at optimal dosage and its toxicity at high dosage. *J. Nutr.* **112**: 1075-1084.
- Young, L.G. R.B. Miller, D.E. Edmeades, A. Lun, G.C. Smith and G.J. King. 1977. Selenium and vitamin E supplementation of high moisture corn diets for swine reproduction. *J. Anim. Sci.* **45**: 1051-1060.

## Chapter 1

**Effect of dietary fat level and vitamin E on energy- and nitrogen  
balances of primiparous lactating sows**

L. Babinszky<sup>1,4</sup>, M. W. A. Verstegen<sup>1</sup>, L. A. den Hartog<sup>3</sup>, W. van der Hel<sup>2</sup>, T. Zandstra<sup>1</sup>,  
E. M. W. van den Elsen<sup>1</sup> and J. T. P. van Dam<sup>1</sup>

<sup>1</sup> Department of Animal Nutrition, Agricultural University Wageningen, Haagsteeg 4, 6708 PM Wageningen, The Netherlands

<sup>2</sup> Department of Animal Husbandry, Agricultural University Wageningen, Marijkeweg 40, 6709 PG Wageningen, The Netherlands

<sup>3</sup> Research Institute for Pig Husbandry, P.O.Box 83, 5240 AB Rosmalen, The Netherlands

<sup>4</sup> Research Institute for Animal Nutrition, H-2053 Herceghalom, Hungary

## Effect of dietary fat level and vitamin E on energy- and nitrogen balances of primiparous lactating sows

### Abstract

A total of 63 primiparous hybrid sows were used in two experiments to study the effect of different fat and vitamin E levels in the lactation diet on the energy balance [EB] and nitrogen balance [NB] of animals. The experiments were used to measure the efficiency of milk production of sows from metabolizable energy of feed. In experiment 1 the major difference in energy sources in the lactation diets were tapioca starch or animal fat. Fifteen sows received the low-fat diet (starch and fat content: 396; 43 g/kg DM) and 16 sows were fed a moderate fat-level diet (starch and fat content: 286; 75 g/kg DM) during 4 weeks of lactation. In experiment 2 cornstarch (200 g/kg) was substituted by animal fat. Sixteen sows were fed during 4 weeks of lactation a low-fat diet (starch and fat content: 418; 37 g/kg DM) and 16 were fed a high-fat diet (starch and fat content: 266; 125 g/kg DM). Vitamin E contents in experiment 1 were: 14 or 126 mg/kg diet and in experiment 2: 22 or 151 mg/kg diet. In both experiments EB and NB of sows were measured between days 18 and 25 of lactation in respiration chambers. It was concluded that sows fed a high level of dietary fat produced more milk energy ( $P < 0.05$ ). The efficiency of milk production from ME was improved ( $P < 0.05$ ) with high dietary fat compared to low-fat diet. Animals fed the high fat level had a more negative EB ( $P < 0.05$ ) when ME intake was controlled. The NB was not affected by the dietary fat levels. The dietary vitamin E did not improve the traits tested.

**Key Words:** Sow, Fat, Vitamin E, Energy balance, Nitrogen balance.

### Introduction

Weight losses of sows during lactation can vary considerably. In cases where sows do not consume sufficient energy for milk production and/or when they have a large litter size they are in negative energy balance (Drochner, 1989). This negative energy balance of sows during lactation may affect the change in body weight and its composition (Lange et al., 1980). Body condition may be particular problem in primiparous sows. Low lactation feed intake in these sows leads to mobilization of their body reserves for milk production. It is thought that this may affect the subsequent reproductive cycle (Mullan and Williams, 1989). Fat and protein mobilized can vary considerably (Mullan and Williams, 1990) and this is influenced by the diet. The energy density of sow's diet can be increased by adding fat, oil or carbohydrate to the diets. Many workers showed that the addition of fat to poultry diets improved feed efficiency more than expected from the increased metabolizable energy (Vermeersch

and Vanschoubroeck, 1968; Jensen et al., 1970). This effect has been referred to an "extracaloric" effect of fat. Several studies have shown that the addition of fat to sow diets during late gestation and/or lactation may increase the concentration of fat in colostrum and milk (Pettigrew, 1981; Britt, 1986). In some experiments in literature the milk production of sows was also increased (Pettigrew, 1981; Coffey et al., 1982). Other investigations, however, have shown that the addition of fat does not improve lactational performance of sows fed a low level of energy intake in comparison with other forms of energy in isocaloric diets e.g. cornstarch (Nelssen et al., 1985). In most studies the performance of sows and piglets and the composition of milk have been measured. However, only limited information is available on the energy metabolism of lactating sows when fed different levels of dietary fat.

Therefore, two experiments were conducted with primiparous sows to determine the effects of different dietary fat levels in the lactation diet on the energy- and nitrogen balances and on the efficiency of milk production.

## Materials and Methods

### *Experiment I(Exp.I)*

**Animals.** A total of 32 first litter PIC (Pig Improvement Company, England) hybrid sows were assigned to four batches of 8 animals each. One animal had to be removed from the experiment at day 14 of lactation.

**Experimental Design and Diets.** In two basal diets the major difference in energy sources were tapioca starch (low-fat diet; Tst) or animal fat (moderate-fat diet: A). The animal fat was slaughtering waste, packing house by-product (Nederlandse Thermo-Chemische Fabrieken, The Netherlands). Both basal diets contained low levels of vitamin E [vit. E], [L] (13 and 16 mg of  $\alpha$ -tocopherol per kg feed). In high level diets [H], these were supplemented with DL- $\alpha$ -tocopheryl acetate to levels of vit. E of 117 and 135 mg  $\alpha$ -tocopherol per kg feed respectively (average analysed values, Table 1). The animals in batches 1 and 4 were fed diets LTst or LA those in batches 2 and 3 diets HTst or HA. In each batch four animals were fed the same dietary composition.

**Feeding and Housing.** During pregnancy gilts were fed 22 MJ NE/day (2.4 kg feed/day) of a diet contained 15 mg of vit. E/kg feed. This energy intake level of about 1.2 times of maintenance is in accordance with recommendation of ARC (1981). This level was also chosen to prevent low feed intake during lactation. The experiment started after farrowing and lasted until weaning after 4 weeks of lactation. Sows received the experimental diets during lactation from one day after farrowing onwards. During lactation each sow was fed a maintenance level of feed, assumed to be 1 % of body weight, plus 0.4 kg per piglet for lactation (Babinszky et al., 1990, unpublished data), thus we

Table 1. Experimental arrangements

Exp. <sup>a</sup>	Treatment (Code)			
	Energy source in sows' diet	In sows' diet (g/kg DM) <sup>b</sup>		In sows' diet (mg/kg diet) <sup>c</sup> Vit.E
		Starch	Fat	
1	Tapioca starch (Tst)	396	43	13 low level (L)
	Tapioca starch (Tst)	396	43	117 high level(H)
	Animal fat (A)	286	75	16 low level (L)
	Animal fat (A)	286	75	135 high level(H)
2	Cornstarch (Cst)	418	37	21 low level (L)
	Cornstarch (Cst)	418	37	140 high level(H)
	Animal fat (A)	266	125	24 low level (L)
	Animal fat (A)	266	125	163 high level(H)

<sup>a</sup> Experiment.

<sup>b</sup> Average analysed values.

<sup>c</sup> As  $\alpha$ -tocopherol (analysed values). In exp.2 in animal fat group 0.868 kg diet contains a same amount of vit. E as 1 kg diet in starch group.

standardized at same energy intake. The main composition of lactation diets is given in Table 2. Creep feed was not provided. Litter size after farrowing was standardized to 10 piglets in batch 1 and to 9 piglets in batches 2, 3 and 4. On day 110 of gestation each gilt was moved to a farrowing barn and placed in a farrowing crate until day 13 of lactation. Between days 14 and 27 of lactation (until weaning) the 8 sows of each batch with their piglets were assigned to two climate-respiration chambers (80 m<sup>3</sup> each). Sows were housed individually in metabolic cages (4 sows on the same diet with their piglets per chamber).

**Energy- and Nitrogen Balance of Sows.** Measurements of the energy- and nitrogen balance of sows were made in the respiration chambers. After 4 days of adaptation to the respiration chamber energy balances [EB] and nitrogen balances [NB] of sows were determined from energy and N in feed, feces, urine and milk over a 7 day collection period, which was between days 18 and 25 of lactation. N balance was corrected for NH<sub>3</sub> escaping in the air, for condensated water and for N content of dust on airfilter. During the 7 day balance period, two respiration measurements were made in 9 min intervals during periods of 48 h and 72 h, respectively. Heat production (sows plus piglets per chamber) was determined indirectly by measuring of the CO<sub>2</sub> produced and the O<sub>2</sub> consumed (Versteegen et al. 1987). The heat production of sows [HP] was derived from the total heat production (sows plus piglets per chamber) by subtracting heat production of piglets. Heat production of piglets was calculated by assuming efficiencies for milk to piglet EB is 0.95 as found by Jordan (1971). Daily

Table 2. Major components of diets for lactating sows (Exp.1 and 2)

Composition g/kg	Experiment 1		Experiment 2	
	Diet 1 <sup>a</sup>	Diet 2 <sup>b</sup>	Diet 1 <sup>a</sup>	Diet 2 <sup>b</sup>
Hominy feed	77	150	-	-
Corn	103	30	-	-
Sunflower seed	85	36	-	-
Soya bean meal, solv.extr.	80	125	97	112
Soya bean, heat treated	68	29	-	-
Soya bean meal, toasted	-	-	48	55
Barley	-	-	56	65
Rapeseed meal	-	-	30	35
Sunflower meal	-	-	150	173
Wheat middlings	-	-	42	48
Peas	65	58	-	-
Tapioca meal	386	196	266	306
Corn starch	-	-	200	-
Animal fat	-	37	10	90
Vitamin-mineral premix <sup>c</sup>	7.5	7.5	5.0	5.8
Other components <sup>d</sup>	128.5	331.5	96.0	110.2

## Nutrient content

as analysed (g/kg DM)

Crude protein	188	193	194	217
Crude fat	43	75	37	125
Starch	396	286	418	266
as calculated				
Netto energy for swine <sup>e</sup> , MJ/kg DM	10.0	10.0	10.1	11.6
Digestible lysine <sup>f</sup> , g/kg DM	7.44	7.44	7.56	8.70

<sup>a,b</sup> Both diets in both experiments contained low and high vitamin E level as stated in Table 1. In experiment 2 0.868 kg of Diet 2 contains the same amount of ingredients and nutrients apart from starch and fat content as 1 kg of Diet 1.

<sup>c</sup> 1 kg basal premix contains in exp.1: DL-alpha-tocopheryl acetate 2000 mg, selenium 27 mg. See also Babinszky et al.(1992).

In exp.2: DL-alpha-tocopheryl acetate 2400 mg, selenium 20 mg. See also Babinszky et al.(1991).

<sup>d</sup> Exp.1: Details of other components have been reported by Babinszky et al. (1992). Exp.2: alfalfa meal, cane molasses, meat meal tankage, DL-methionine, DL-lysine, monocalcium phosphate, salt.

<sup>e</sup> According to the Rostock net energy system: Centraal Veevoederbureau (CVB,1988).

<sup>f</sup> Faecal digestibility (CVB, 1988).

maintenance requirement of piglets was assumed as  $450 \text{ kJ/kg}^{0.75}$  according to Verstegen et al.(1985). For the statistical analysis one average value of daily HP or EB per chamber ( $\text{kJ/W}^{0.75}$ ) was used. Calorimeter conditions throughout the experiment were maintained at 18 °C air temperature and 65%

relative humidity. The light regimes in chambers were 12 hrs L (light) - 12 hrs D (dark). Light was on from 0700 until 1900. Heat lamps were used for piglets and placed at about 60 cm above the floor in each crate in the farrowing barn and also in respiration chambers.

**Milk Production of Sows.** Milk production of sows was measured by weighing piglets before and after various sucklings at days 16, 21 and 26 of lactation. The milk production of sows per suckling was obtained from 5 to 6 consecutive measurements at one-hour intervals on one measuring day. Multiplying by 24 gave the daily milk production, assuming 24 sucklings per day. It was found from peaks in heat production that piglets suckled about 24 times per day (Chapter 2). For the calculation of milk yield, corrections for weight loss of piglets due to metabolic rate, evaporations, urinations and defecations during suckling were applied (Babinszky et al., 1992). The total milk production of sows during the balance period was estimated from the mean daily milk production of the three measurement days. Multiplying by duration of the balance (7 days) resulted in the total milk yield during balance.

**Calculation of Daily Protein- and Fat Gain of Sows.** The protein and fat gain of sows (g/d per sow) during the balance period were calculated by the following formulas:

$$\text{Protein gain: } (NB \times 6.25) \times W^{0.75};$$

$$\text{Fat gain : } ((EB - (\text{protein gain} \times 23.85) / 39.75) \times W^{0.75})$$

where: NB= daily nitrogen balance of sow (g N/kg<sup>0.75</sup>); EB= daily energy balance of sow (kJ/kg<sup>0.75</sup>); W<sup>0.75</sup>= average metabolic weight of sow during balance; 23.85 kJ/g and 39.75 kJ/g are respectively calorific values of protein and fat (Brouwer, 1965).

**Estimation of Daily Gain of Sows.** The daily gain of sows during balance period was computed from protein and fat gain since only short period (7 days) are involved. The calculation was done as follows:

$$\text{Daily gain of sow (g)} = (\text{protein gain} \times 4) + (\text{fat gain} \times 0.95)$$

According to van Es and Boekholt (1987) the deposition of 1 g protein involves a weight gain of about 4 g. However, a deposition of 1 g fat may result in a live weight change of only 0.90 - 0.95 g.

**Estimation of Efficiency of Milk Production of Sows from Feed.** We assumed that energy source (dietary fat level) has a bigger effect on efficiency than on ME need for maintenance (ME<sub>m</sub>), because feeding level is about 4 times higher than maintenance requirement. Therefore, the efficiency of milk production from feed ME was calculated in the following way:

All ME intakes were corrected to a zero EB. This means that all milk production was to be related to ME intake and not from body stores. Calculations were made as follows:

$$\text{For EB} < 0: \text{ME}_c = \text{ME} - (1/0.80) \times \text{EB}$$

(0.80 was taken from Verstegen et al. (1985))

The factor of 0.80 reflects the assumption that 0.80 MJ of energy from the body is as effective in supporting milk production as is 1 MJ of dietary ME.

$$\text{For EB} > 0: \text{ME}_c = \text{ME} - (1/0.70) \times \text{EB}$$

(0.70 as efficiency of EB from ME was taken from Verstegen (1971))

where:  $\text{ME}_c$  = ME intake corrected to zero EB; ME = daily ME intake (kJ/kg<sup>0.75</sup>); EB = daily energy balance (kJ/kg<sup>0.75</sup>).

In the literature varying values for  $\text{ME}_m$  are being reported with different efficiencies. We assumed from literature a value of 420 kJ ME/kg<sup>0.75</sup> for the daily maintenance requirement. The efficiency of milk production was calculated in the following way in both experiments for all treatment groups:

$$\text{Eff}_{\text{mp}} = \text{LE} / (\text{ME}_c - \text{ME}_m)$$

where:  $\text{Eff}_{\text{mp}}$  = efficiency of milk production; LE = daily lactation energy (kJ/kg<sup>0.75</sup>);  $\text{ME}_c$  = daily ME intake corrected to zero EB;  $\text{ME}_m$  = daily maintenance requirement (420 kJ ME /kg<sup>0.75</sup>).

For the statistical analysis of efficiency of milk production one mean value per chamber was used.

**Milk- and Feed Sampling.** Milk samples were obtained from sows and from all functional teats of sows at day 14 of lactation and at weaning (27 day of lactation) using an injection of oxytocin according to the method described by Babinszky et al.(1991). Experimental diets were sampled for analysis of nutrient content two times each week.

**Weight and Backfat Thickness of Sows.** Sows were weighed individually after farrowing, before and at the end of balance period and at weaning. The backfat thickness of sows was measured ultrasonically after farrowing and also at weaning.

**Feed, Milk, Feces and Urine Analysis.** The nutrient content of diets (dry matter, crude protein, crude fat, starch) and the composition of milk (dry matter, protein, fat, and ash) was analysed as reported Babinszky et al. (1991, 1992). Lactose content of milk was calculated by subtracting fat, protein and ash from dry matter content.

In feces samples from sows, dry matter was measured according to ISO 6496 (1983). Nitrogen content of feces samples was measured by Kjeldahl method in fresh samples (ISO 5983, 1979). In urine samples from sows nitrogen content was measured in fresh samples according to ISO 5983 (1979). Gross energy content of feed, feces and urine samples was measured by bomb calorimetry (IKA C 700 T; IKA-Werk, Staufen, Germany). Energy content of milk was calculated on the basis of fat, protein and lactose content in samples according to the formula of Klaver et al. (1981). In 12 samples per experiment the energy content was measured both by bomb calorimetry (IKA C 700 T) and calculated also according to Klaver et al. (1981). We found a very high correlation between calculated and measured values of energy content in milk ( $R^2 = 0.98$  in exp.1 and  $0.99$  in exp.2).

Alpha-tocopherol content in feed was analysed by the high performance liquid chromatography (HPLC) method (Hoffmann-La Roche Laboratory, Basle, Switzerland) as described by Manz and Philipp (1981).

### ***Experiment 2 [Exp.2]***

***Animals.*** A total of 32 first litter PIC hybrid sows were used in four subsequent batches of 8 animals each.

***Experimental Design and Diets.*** In this experiment two basal diets (low and high fat content diets) were used. In low fat content diet energy source was mainly cornstarch [Cst]. In high fat content diet Cst (200 g/kg) was substituted for animal fat [A]. The animal fat was the same product as described in exp.1. Both basal diets contained low levels of vit. E [L] (21 and 24 mg of  $\alpha$ -tocopherol /kg feed) and these diets were supplemented with DL- $\alpha$ -tocopheryl acetate to high level of vit. E [H] (140 and 163 mg of  $\alpha$ -tocopherol / kg diet, Table 1). The main components of basal diets can be seen in Table 2. The diet with high fat was not diluted with extra crude fibre or otherwise. Therefore in the high-fat diet 0.868 kg contained the same amounts of nutrients apart from fat and starch content and also a similar amount of  $\alpha$ -tocopherol as 1 kg of low-fat diet. The animals in batches 1 and 4 received diets LCst or LA and in batches 2 and 3 the diets were HCst or HA (Table 2). In each batch four animals were fed the same diet.

***Feeding.*** During pregnancy gilts were fed as described in experiment 1. The experiment started after farrowing and lasted until weaning (27 days of lactation). The sows received the experimental diets from one day after farrowing till weaning. Daily feed ration of sows in low fat group was calculated as in experiment 1. In the high fat group sows received 86.8 % of on this way calculated amount of diet to standardize on energy intake. Creep feed was not provided during suckling period. After parturition, the litters were standardized to 9 piglets in all batches.

**Housing of Animals and Experimental Procedures.** Housing of animals and experimental procedures were the same as in exp.1. Also, the measurement of EB, NB and milk production (on days 16 and 26 of lactation), estimation of efficiency of milk production were identical. Moreover analyses of feed, milk, feces and urine samples were also identical to those in exp.1.

**Statistical Analysis.** Data of both experiments were analysed in the following way:

In each batch of sows the effect of dietary fat level has been tested directly since only one vit. E level was used in each batch. This means that a part of the variation between batches is also associated with dietary vit. E level. Therefore, we nested the batches within dietary vit. E level. In this way the dietary fat level can be tested correctly. We tested the vit. E effect against the batch variation within vit. E levels. Since in both experiments, no significant interaction between energy source and vit. E level was found the following model was used:

$$Y_{ijkl} = \mu + A_i + B_j + C(B)_{k(j)} + e_{ijkl}$$

where:  $Y_{ijkl}$ = dependent variable;  $\mu$ = mean;  $A_i$ = fat level in sow's diet ( $i=1, 2$ );  $B_j$ = vit. E in sow's diet ( $j=1, 2$ );  $C(B)_{k(j)}$ = batch variation within vit. E levels ( $k(j)=1, 2, 3, 4$ );  $e_{ijkl}$ = residual error. Analysis of variance was done by GLM procedure (SAS, 1990) for all variables in both experiments.

## Results and Discussion

The results of both experiments are reported per fat level in the lactating sow's diet because no effect of vit. E was found.

**Live Weight and Backfat Thickness of Sows.** Data on live weight change of sows during lactation are given in Table 3. Differences between treatment groups in both experiments with regard to live weight of sows post partum, at start and end of balance and at weaning were not significant.

Cox et al. (1983) reported that sows fed a control diet (no additional fat) or 10% fat supplemented diets ad libitum lost weight during lactation on both diets. In the summer experiment no difference between control and treatment group were noticed. However, in the winter trial sows fed the fat-supplemented diet, lost more weight ( $P < 0.05$ ) than control animals. Schoenherr et al. (1989) concluded from their results, that sow weight change during a 22 day lactation period was not affected by diets containing starch or fat both in a thermoneutral (20 °C) or a hot (32 °C) environment. However, it should be noted that in these trials animals were allowed ad libitum consumption. In these investigations the fat-supplemented diets had a somewhat higher ME intake than the control diet.

**Table 3. Effect of dietary fat level on the body weight of sows (kg) during lactation**

Item	Experiment 1			Experiment 2		
	Energy source <sup>a</sup>		RMSE <sup>b</sup>	Energy source <sup>a</sup>		RMSE <sup>b</sup>
	Tst	A		Cst	A	
n (sows)	15	16		16	16	
Body weight						
After farrowing	167.7	168.7	17.8	170.2	169.2	9.9
Balance start	162.4	161.4	18.9	158.1	157.0	8.4
Balance end	161.1	160.9	19.4	155.7	152.7	7.9
At weaning	159.6	158.3	18.4	150.8	147.1	8.0

<sup>a</sup> Codes are defined in Table 1.

<sup>b</sup> Root mean square error.

In our experiment we avoided this difference by giving fixed energy intake based on litter size. Nelssen et al. (1985) found that sows fed a diet with tallow from late gestation until the end of 4 weeks of lactation lost more weight ( $P < 0.05$ ) during lactation than those fed a diet with cornstarch. They concluded that the short adaptation period (6 days) to the diet with animal fat resulted in poor digestion of the animal fat. Consequently a larger weight loss of these sows accrued. Additionally, feeding the fat resulted in an increased lipid content in the milk. Restricted intake of energy during lactation and this shunting of energetic substances directly to the milk may result in increased weight loss of sows. In our study the animals also received the experimental diets for a relatively short period (4 weeks of lactation). We also found higher fat content in milk from sows fed high-fat diet in exp.2 (Chapter 3). In our study in exp.2, however, the digestibility of fat in high-fat group was higher than in low-fat group (Chapter 3). This indicates that in our study the weight loss in sows fed high-fat diet (exp. 2) is not related to a lowered digestibility of fat.

The changes in backfat thickness of sows are summarized in Table 4. From this table it can be seen that in both experiments the applied levels of dietary fat had no effect on the backfat thickness. Nelssen et al. (1985) reported that sows fed tallow tended to lose more backfat than sows in cornstarch group, but the difference was not significant.

**Energy Balance of Sows.** Data on energy balance are given in Table 5. The daily gross energy (GE) and ME intake of sows ( $\text{kJ}/\text{kg}^{0.75}$ ) in exp.1 were similar in both treatment groups. The energy in feces from animals fed moderate-fat diet was higher ( $P < 0.05$ ) than from animals in the low-fat group. The energy in urine and milk and in HP were not affected by the diets. Therefore similar (negative) energy balances were found in both experimental groups. Digestibility (DE/GE) and metabolizability (ME/GE) of energy in the moderate-fat treatment were lower ( $P < 0.05$ ) than in low-fat group.

**Table 4. Effect of dietary fat level on the backfat thickness of sows during lactation (mm)**

Item	Experiment 1			Experiment 2		
	Energy source <sup>a</sup>		RMSE <sup>b</sup>	Energy source <sup>a</sup>		RMSE <sup>b</sup>
	Tst	A		Cst	A	
n (sows)	15	16		16	16	
After farrowing	18.9	17.9	3.5	17.5	17.8	3.3
At weaning	15.3	14.0	2.8	13.4	13.1	2.4

<sup>a</sup> Codes are defined in Table 1.

<sup>b</sup> Root mean square error.

**Table 5. Effect of dietary fat level on the daily energy balance of sows between 18 and 25 days of lactation (kJ/kg<sup>0.75</sup>)**

Item	Experiment 1			Experiment 2		
	Energy source <sup>a</sup>		RMSE <sup>b</sup>	Energy source <sup>a</sup>		RMSE <sup>b</sup>
	Tst	A		Cst	A	
n (sows)	15	16		16	16	
GE intake	2006	2083	203	1789	1802	125
ME intake	1605	1626	160	1454	1404	112
Feces energy	349 <sup>c</sup>	414 <sup>d</sup>	66	294 <sup>e</sup>	356 <sup>f</sup>	38
Urine energy	51	43	8	41	43	12
Milk energy	1073	1116	211	1019 <sup>g</sup>	1159 <sup>h</sup>	177
Heat production <sup>i</sup>	795	779	20 <sup>j</sup>	771 <sup>g</sup>	719 <sup>h</sup>	18 <sup>j</sup>
Energy balance	-268	-269	58 <sup>j</sup>	-336 <sup>g</sup>	-473 <sup>h</sup>	61 <sup>j</sup>
DE/GE, %	82.7 <sup>c</sup>	80.2 <sup>d</sup>	2.3	83.5 <sup>g</sup>	80.3 <sup>h</sup>	1.8
ME/GE, %	80.1 <sup>c</sup>	78.1 <sup>d</sup>	2.3	81.1 <sup>g</sup>	77.9 <sup>h</sup>	1.7

<sup>a</sup> Codes are defined in Table 1.

<sup>b</sup> Root mean square error.

<sup>c,d</sup> Different superscripts in the same row indicate significant differences among treatment groups in exp.1 ( $P < 0.05$ ).

<sup>e,f</sup> Different superscripts in the same row indicate significant differences among treatment groups in exp.2 ( $P < 0.01$ ).

<sup>g,h</sup> Different superscripts in the same row indicate significant differences among treatment groups in exp.2 ( $P < 0.05$ ).

<sup>i</sup> Heat production of the sows = total heat production minus heat production of piglets.

<sup>j</sup> For statistical analysis  $n = 4$  per treatment.

In exp.2 the GE and ME intake of sows were similar with the starch and fat diets (low and high-fat diet). The feces energy output in this experiment was also higher in high-fat group than in low-fat group ( $P < 0.01$ ). The energy in urine was not affected by the diets. The milk energy production was higher in sows fed high dietary fat than those fed low-fat diet ( $P < 0.05$ ). This higher milk energy output is a consequence of higher fat (energy) content of milk ( $P < 0.05$ ) because the daily milk production of sows was not affected by the different dietary fat levels (Chapter 3). Sows in low-fat group produced more heat, than in high-fat group ( $P < 0.05$ ). The higher feces and milk energy output in high-fat group resulted in more negative EB than in low-fat group ( $P < 0.05$ ). The DE/GE and ME/GE ratios were lower for sows fed high-fat diet than for sows fed low-fat (starch) diet ( $P < 0.05$ ). The results of exp.1 show that the EB was not clearly affected by the moderate fat level. However, in sows fed the high dietary fat level in exp.2, more negative EB was measured than in sows fed the low-fat (starch) diet ( $P < 0.05$ ).

Müller and Kirchgessner (1980) reported no clear differences in energy retention in mature non-pregnant sows between animals fed a diet with no carbohydrates containing only protein and fat and animals fed a mixed diet (carbohydrate plus fat). Also, the HP was similar in both dietary groups. Kirchgessner and Müller (1984) similarly found that, in non-pregnant, non-lactating mature sows, a high-fat diet had no effect on diet-induced thermogenesis compared to a carbohydrate-rich diet. The results of our studies with lactation diets, however, showed that there is an effect on heat production from the fat-rich diet. Our results show that sows fed a high dietary fat level (exp.2) had lower energy digestibility and a higher milk energy output. Therefore, they showed a more negative EB than animals fed the starch (low-fat) diet. At moderate-fat level (exp.1) this difference was not noted. Both in the studies of Kirchgessner and Müller (1984) and in our study the high dietary fat level substantially decreased digestibility of energy compared to a carbohydrate-rich diet. Lellis and Speer (1983) studied multiparous sows receiving diets with 27% dextrose or 15% tallow from day 105 of gestation throughout 21 days of lactation. They measured energy balances from 5 to 10 days of lactation. They also found higher fecal energy output ( $P < 0.005$ ) for sows fed tallow compared to dextrose. The milk energy and EB (without HP) were somewhat higher in sows fed tallow, than in sows received dextrose (however, not significantly). It should be noted that Lellis and Speer (1983) used in their investigation multiparous sows, and that the pregnancy body condition may influence the milk production and also EB.

**Nitrogen Balance of Sows.** Data on N-balance of sows (NB) are given in Table 6. In exp.1 the N digestibility in the moderate-fat group (73.9%) was lower ( $P < 0.05$ ) than in low-fat group (77.0%). However, the daily digestible N intake in both groups was similar (low-fat group: 2.58; moderate-fat group: 2.53 g/kg<sup>0.75</sup> respectively). The N output in urine and milk was not affected by the fat levels.

**Table 6. Effect of dietary fat level on the daily nitrogen balance of sows between 18 and 25 days of lactation (g N/kg<sup>0.75</sup>)**

Item	Experiment 1			Experiment 2		
	Energy source <sup>a</sup>		RMSE <sup>b</sup>	Energy source <sup>a</sup>		RMSE <sup>b</sup>
	Tst	A		Cst	A	
n (sows)	15	16		16	16	
N intake	3.35	3.44	0.34	3.04	3.09	0.21
N in feces	0.78 <sup>c</sup>	0.90 <sup>d</sup>	0.16	0.54	0.55	0.07
N in urine	0.80	0.75	0.12	0.77 <sup>e</sup>	0.90 <sup>f</sup>	0.14
N in milk	1.57	1.62	0.26	1.58	1.66	0.22
N balance	0.10	0.08	0.24	0.04	-0.10	0.29

<sup>a</sup> Codes are defined in Table 1.

<sup>b</sup> Root mean square error.

<sup>c,d</sup> Different superscripts in the same row indicate significant differences among treatment groups in exp.1 ( $P < 0.05$ ).

<sup>e,f</sup> Different superscripts in the same row indicate significant differences among treatment groups in exp.2 ( $P < 0.05$ ).

The NB in both groups was about zero and this was not influenced by the dietary fat. In exp.2 the digestibility of N was not affected by the dietary fat levels. The digestibility of N in the low-fat group was: 82.3% and in the high-fat group was 82.2%. The daily digestible N intake in both experimental groups was similar (in low-fat group: 2.50, in high-fat group 2.54 g/kg<sup>0.75</sup>). The N excretion via urine in the high-fat group in exp.2 was higher ( $P < 0.05$ ) than in low-fat group. The NB in this experiment was also around zero and this was not influenced by the dietary fat levels. On the basis of our results we concluded that the NB of primiparous lactating sows during late lactation was not affected by the dietary fat level.

**Protein Gain and Fat Gain of Sows.** Because the mean metabolic body weight of sows during the balance period in both experiments was similar the daily protein and fat gain and the calculated growth of sows are expressed as g/sow (Table 7). In experiment 1 in both low and moderate-fat groups protein deposition was very small and about 300 g of fat loss per day per sow was calculated. The calculated weight loss was similar in both experimental groups. In exp. 2 in low-fat group there was a small protein deposition, but in the high-fat group a small protein loss was observed (not significant). Sows fed the high dietary fat level in exp.2 lost significantly more fat and weight during the balance measurements than sows fed the low-fat diet.

**Table 7. Effect of dietary fat level on the daily protein and fat gain and weight change of sows between 18 and 25 days of lactation (g/sow)**

Item	Experiment 1			Experiment 2		
	Energy source <sup>a</sup>		RMSE <sup>b</sup>	Energy source <sup>a</sup>		RMSE <sup>b</sup>
	Tst	A		Cst	A	
n (sows)	15	16		16	16	
Body weight, kg <sup>0.75</sup>	45.3	45.1	4.0	44.3	43.9	1.7
Protein gain	30	23	69	11	-28	80
Fat gain	-316	-317	50 <sup>e</sup>	-381 <sup>c</sup>	-506 <sup>d</sup>	67 <sup>e</sup>
Calculated growth	-179	-209	146 <sup>e</sup>	-319 <sup>c</sup>	-595 <sup>d</sup>	113 <sup>e</sup>

<sup>a</sup> Codes are defined in Table 1.

<sup>b</sup> Root mean square error.

<sup>c,d</sup> Different superscripts in the same row indicate significant differences among treatment groups in exp.2 ( $P < 0.05$ ).

<sup>e</sup> For statistical analysis n=4 per treatment.

*Efficiency of Milk Production of Sows.* In exp.1 the efficiency of milk production from ME above maintenance was not affected by the diets (Table 8). In exp.2 the efficiency was higher in the high-

**Table 8. Effect of dietary fat level on the efficiency of milk production from feed**

Item	Experiment 1			Experiment 2		
	Energy source <sup>a</sup>		RMSE <sup>b</sup>	Energy source <sup>a</sup>		RMSE <sup>b</sup>
	Tst	A		Cst	A	
n (sows)	15	16		16	16	
Efficiency <sup>c</sup>	0.71	0.72	0.01 <sup>f</sup>	0.70 <sup>d</sup>	0.73 <sup>e</sup>	0.01 <sup>f</sup>

<sup>a</sup> Codes are defined in Table 1.

<sup>b</sup> Root mean square error.

<sup>c</sup> The daily maintenance requirement of sows was fixed at 420 kJ ME /kg<sup>0.75</sup> for all treatment groups.

<sup>d,e</sup> Different superscripts in the same row indicate significant differences among treatment groups in exp.2 ( $P < 0.05$ ).

<sup>f</sup> For statistical analysis n=4 per treatment.

fat group than in the starch (low-fat) group ( $P < 0.05$ ). The higher efficiency of milk production for sows fed the high dietary fat level may be caused by more efficient production of milk (fat) from dietary fat than from dietary starch because conversion of dietary fat to milk fat requires fewer steps than carbohydrates to milk fat (van Es and Boekholt, 1987).

Noblet et al. (1990) reported that the efficiency of milk production from ME in literature ranges from 68 to 79%, with the mean being 72%. This means that our data for efficiency (70–73%) remained within the normal ranges for sows.

Lellis and Speer (1983) also concluded that efficiency of milk production was higher ( $P < 0.005$ ) for multiparous sows fed tallow than for sows fed dextrose. In their investigation, however, many assumptions were adopted for the calculations of efficiency. The results of both studies indicate that a high level of fat in the lactation diet may have a beneficial effect on the efficiency of energy in milk production.

*In conclusion*, it can be stated that feeding a high level of fat in the lactation diet causes sows to produce more milk energy ( $P < 0.05$ ) and the efficiency of milk production from ME is improved ( $P < 0.05$ ). However, if ME intake is not increased these animals may have more weight loss (body fat loss) during lactation and they have more negative energy balance. The nitrogen balance was not affected by the different levels of dietary fat. The results of present study also indicate that the moderate-fat level in the lactation diet did not improve the traits tested compared to the low-fat level.

## Implications

The present study on different fat levels in the lactating sow's diet shows that there may be a reason to use a high dietary fat level in order to increase the milk energy production.

In practical conditions this increased milk energy production means, that dietary ad libitum intake during lactation also plays a major role in sows because it determines how much body stores have to be used for milk production. The results also indicate that by feeding a high level of dietary fat the efficiency of milk production from feed ME is also improved. This improved efficiency of milk production of sows may have however, a favorable effect on the profitability of pig production. The dietary vitamin E did not improve the traits tested.

## References

- ARC. 1981. Agricultural Research Council. The Nutrient Requirements of Pigs. Commonwealth Agricultural Bureaux, Slough.
- Babinszky, L., D.J. Langhout, M.W.A. Verstegen, L.A. den Hartog, P. Joling and M. Nieuwland. 1991. Effect of  $\alpha$ -tocopherol and dietary fat source on some blood and immunological variables in lactating sows. *Anim. Prod.* 52: 367-375.
- Babinszky, L., D.J. Langhout, M.W.A. Verstegen, L.A. den Hartog, T. Zandstra, P.L.G. Bakker and J.A.A.M. Verstegen. 1992. Dietary vitamin E and fat source and lactating performance of primiparous sows and their piglets. *Livest. Prod. Sci.* 30: 155-168.
- Britt, J.H. 1986. Improving sow productivity through management during gestation, lactation and after weaning. *J. Anim. Sci.* 63: 1288-1296.
- Brouwer, E. 1965. Report of sub-committee on constants and factors. In: K. L. Blaxter (Ed) Energy Metabolism. pp. 441-443. EAAP Publication No. 2. Academic Press Inc., London.
- Coffey, M.T., R.W. Seerley and J.W. Mabry. 1982. The effect of source of supplemental dietary energy on sow milk yield, milk composition and litter performance. *J. Anim. Sci.* 55: 1388-1394.
- Cox, N.M., J.H. Britt, W.D. Armstrong and H.D. Alhusen. 1983. Effect of feeding fat and altering weaning schedule on rebreeding in primiparous sows. *J. Anim. Sci.* 56: 21-29.
- CVB. 1988. Dutch Feeding Tables [in Dutch]. Centraal Veevoederbureau, The Netherlands.
- Drochner, W. 1989. Einflüsse von Fettzulagen an Sauen auf Aufzuchtleistung und Fruchtbarkeit [in German]. *Übers. Tierernährg.* 17: 99-138.
- Es, A.J.H. van and H.A. Boekholt. 1987. Energy metabolism of farm animals. In: M.W.A. Verstegen and A.M. Henken (Eds) Energy Metabolism in Farm Animals. pp.3-19. Martinus Nijhoff Publishers, Dordrecht.
- ISO. 1979. Animal Feeding Stuffs: Determination of nitrogen content and calculation of crude protein content. ISO 5983. International Organization for Standardization.
- ISO. 1983. Animal Feeding Stuffs: Determination of moisture content. ISO 6496. International Organization for Standardization.
- Jensen, L.S., G.W. Schumaier and J.D. Latshaw. 1970. "Extra caloric" effect of dietary fat for developing turkeys as influenced by calorie-protein ratio. *Poul. Sci.* 49: 1697-1704.
- Jordan, J.W. 1971. Investigations into the energy metabolism of bacon pigs and piglets. *Agr. Progress* 46: 9-25.
- Kirchgessner, M. and H.L. Müller. 1984. Thermogenese bei Verabreichung einer ketogenen Diät im Modellversuch an Sauen [in German]. *Int. J. Vitam. Nutr. Res.* 54: 99-106.
- Klaver, J., G.J.M. van Kempen, P.G.B. de Lange, M.W.A. Verstegen and H. Boer. 1981. Milk composition and daily yield of different milk components as affected by sow condition and lactation/feeding regimen. *J. Anim. Sci.* 52: 1091-1097.
- Lange, P.G.B. de, G.J.M. van Kempen, J. Klaver and M.W.A. Verstegen. 1980. Effect of condition of sows on energy balances during 7 days before and 7 days after parturition. *J. Anim. Sci.* 50: 886-891.
- Lellis, W.A. and V.C. Speer. 1983. Nutrient balance of lactating sows fed supplemental tallow. *J. Anim. Sci.* 56: 1334-1339.
- Manz, U. and K. Philipp. 1981. A method for the routine determination of tocopherols in animal feed and human foodstuffs with the aid of high performance liquid chromatography. *Int. J. Vitam. Nutr. Res.* 51: 342-348.
- Mullan, B.P. and I.H. Williams. 1989. The effect of body reserves at farrowing on the reproductive performance of first-litter sows. *Anim. Prod.* 48: 449-457.
- Mullan, B.P. and I.H. Williams. 1990. The chemical composition of sows during their first lactation. *Anim. Prod.* 51: 375-387.

- Müller, H.L. and M. Kirchgessner. 1980. Energy utilization of a carbohydrate-free protein-fat diet by sows. In: L.E. Mount (Ed) Energy Metabolism. pp. 249-252. EAAP Publication No.26. Butterworths, London.
- Nelssen, J.L., A.J. Lewis, E.R. Peo, Jr. and B.D. Moser. 1985. Effect of source of dietary energy and energy restriction during lactation on sow and litter performance. *J. Anim. Sci.* 60: 171-178.
- Noblet, J., J.Y. Dourmad and M. Etienne. 1990. Energy utilization in pregnant and lactating sows: modeling of energy requirements. *J. Anim. Sci.* 68: 562-572.
- Pettigrew, J.E.Jr. 1981. Supplemental dietary fat for periparturient sows: a review. *J. Anim. Sci.* 53: 107-117.
- SAS. 1990. SAS User's Guide: Statistics. SAS Inst., Inc., Cary, NC.
- Schoenherr, W.D., T.S. Stahly and G.L. Cromwell. 1989. The effects of dietary fat or fiber addition on yield and composition of milk from sows housed in a warm or hot environment. *J. Anim. Sci.* 67: 482-495.
- Vermeersch, G. and F. Vanschoubroek. 1968. The quantification of the effect of increasing levels of various fats on body weight gain, efficiency of food conversion and food intake of growing chicks. *Brit. Poul. Sci.* 9: 13-30.
- Verstegen, M.W.A. 1971. Influence of environmental temperature on energy metabolism of growing pigs housed individually and in groups. Thesis. Agric. Univ. Wageningen, The Netherlands.
- Verstegen, M.W.A., J. Mesu, G.J.M. van Kempen and C. Geerse. 1985. Energy balances of lactating sows in relation to feeding level and stage of lactation. *J. Anim. Sci.* 60: 731-740.
- Verstegen, M.W.A., W. van der Hel, H.A. Brandsma, A.M. Henken and A.M. Bransen. 1987. The Wageningen respiration unit for animal production research: a description of the equipment and its possibilities. In: M.W.A. Verstegen and A.M. Henken (Eds) Energy Metabolism in Farm Animals. pp. 21-48. Martinus Nijhoff Publishers, Dordrecht.

## Chapter 2

**Metabolic rate of primiparous lactating sows and suckling piglets  
as affected by dietary fat level and vitamin E**

L. Babinszky<sup>1,4</sup>, M.W.A. Verstegen<sup>1</sup>, H.A. Brandsma<sup>2</sup>, W. van der Hel<sup>2</sup>, and L.A.den Hartog<sup>3</sup>

<sup>1</sup> Department of Animal Nutrition, Agricultural University Wageningen, Haagsteeg 4, 6708 PM Wageningen, The Netherlands

<sup>2</sup> Department of Animal Husbandry, Agricultural University Wageningen, Marijkeweg 40, 6709 PG Wageningen, The Netherlands

<sup>3</sup> Research Institute for Pig Husbandry, P.O.Box 83, 5240 AB Rosmalen, The Netherlands

<sup>4</sup> Research Institute for Animal Nutrition, H-2053 Herceghalom, Hungary

## Metabolic rate of primiparous lactating sows and suckling piglets as affected by dietary fat level and vitamin E

### Abstract

A total of 63 primiparous lactating sows were used in two experiments to study the effect of different fat and vitamin E levels in the diet on heat production of sows [HP]. Heat production associated with suckling in piglets was estimated. In experiment 1, the major difference in energy sources in the lactation diets were tapioca starch or animal fat. Fifteen sows received the low-fat diet (starch and fat content: 396; 43 g/kg DM) and 16 sows were fed a moderate fat-level diet (starch and fat content: 286; 75 g/kg DM) during 4 weeks of lactation. In experiment 2, 20% cornstarch was substituted by animal fat. For 4 weeks of lactation sixteen sows were fed a low-fat diet (starch and fat content: 418; 37 g/kg DM) and 16 were fed a high-fat diet (starch and fat content: 266; 125 g/kg DM). Vitamin E contents in experiment 1 were 14 or 126 mg/kg diet, and in experiment 2, 22 or 151 mg/kg diet. In both experiments, HP (sows plus piglets) was measured indirectly by measurement of CO<sub>2</sub> production and O<sub>2</sub> consumption between day 18 and 25 of lactation. It was found that sows fed a high level of dietary fat produced less heat ( $P < 0.05$ ) and their respiratory quotients were lower ( $P < 0.05$ ) than sows fed low dietary fat (carbohydrate-rich diet). The extra energy requirement of suckling for piglets above basic level of HP was estimated as 1092 kJ/kg<sup>0.75</sup>. The number of peaks of HP indicated that piglets suckle at about hourly intervals. Traits were not affected by the dietary vitamin E levels.

Key Words: Sow, Piglet, Fat, Vitamin E, Metabolic rate, Lactation.

### Introduction

Numerous researchers have studied the effects of added dietary fat on lactation performance in sows. Reviews were given by Moser and Lewis (1980), Pettigrew (1981) and Drochner (1989). The studies from literature show that the addition of fat to the diet during late gestation and/or lactation may increase the concentration of fat in colostrum and milk (Pettigrew, 1981; Britt, 1986). In some experiments the milk production of sows was increased also (Pettigrew, 1981; Coffey et al., 1982). In other trials, however, the addition of fat did not clearly improve litter performance during lactation, neither in restricted fed sows (Nelssen et al., 1985) nor in those fed ad libitum (Boyd et al., 1982). In most studies performance traits of sows, piglets and composition of milk were measured during ad libitum feeding. Results showed that the response to fat was variable. Several papers also reported the effect of dietary fat on heat production in pigs. Kirchgessner and Müller (1984) reported

that in non-pregnant, non-lactating sows, a high-fat diet had no effect on thermogenesis compared to a carbohydrate-rich diet. On the other hand, Hillcoat and Annison (1974) found that heat production in growing pigs tended to decrease with increasing dietary fat level. In the literature very little information is available on the energy metabolism and heat production of lactating sows and suckling piglets, when sows were fed different levels of dietary fat.

Therefore, a study was conducted to evaluate the effect of dietary fat level in the lactation diet on the heat production of primiparous lactating sows and their piglets.

## Materials and Methods

### *Experiment 1 [Exp.1]*

#### *Animals*

A total of 32 first litter PIC (Pig Improvement Company, England) hybrid sows were assigned to four batches of 8 animals each. One animal had to be removed from the experiment at day 14 of lactation.

#### *Experimental Arrangements and Diets*

In two basal diets the major difference in energy sources were tapioca starch (low-fat diet: St) or animal fat (moderate-fat diet: A). The animal fat was slaughtering waste, packing house by-product (Nederlandse Thermo-Chemische Fabrieken). Both diets contained a low level of vitamin E [L] (13 and 16 mg of  $\alpha$ -tocopherol per kg feed) and a high level of vitamin E [H] (117 and 135 mg  $\alpha$ -tocopherol per kg feed). The vitamin E was added as DL- $\alpha$ -tocopheryl acetate (Table 1.). Animals in two batches (1 and 4) were fed diets LSt and LA in two other batches (2 and 3) diets HSt and HA. Four animals in each batch received the same diet.

#### *Feeding and Housing*

During pregnancy, gilts were fed at a level of 1.2 times maintenance (2.4 kg diet/day; 22 MJ NE/day) according to ARC (1981) recommendations. This feeding level is sufficient for maintenance and about 50 kg of gain (reproduction plus maternal) during pregnancy. The pregnancy diet contained 15 mg of  $\alpha$ -tocopherol per kg feed. On day 100 of pregnancy, gilts were moved to the farrowing barn and placed in individual farrowing crates until day 13 of lactation. The experiment started after farrowing and lasted until weaning 4 weeks of lactation. Sows received the experimental diets from one day after farrowing until weaning at 27 days of lactation. During lactation, sows were fed maintenance feed (assumed 1% of body weight) and in addition 0.4 kg per piglet for lactation (Babinszky et al., unpublished data). The composition of lactation diets is given in Table 2. Creep feed was not provided during suckling. Litter size after farrowing was standardized to 10 piglets in batch 1 and to 9 piglets in batches 2, 3 and 4.

Table 1. Experimental arrangements

Exp. <sup>a</sup>	Energy source in sows' diet		Treatment (Code)		In sows' diet (mg/kg diet) <sup>c</sup> Vit.E	
			In sows' diet (g/kg DM) <sup>b</sup>			
			Starch	Fat		
1	Tapioca starch	(St)	396	43	13	low level (L)
	Tapioca starch	(St)	396	43	117	high level(H)
	Animal fat	(A)	286	75	16	low level (L)
	Animal fat	(A)	286	75	135	high level(H)
2	Cornstarch	(St)	418	37	21	low level (L)
	Cornstarch	(St)	418	37	140	high level(H)
	Animal fat	(A)	266	125	24	low level (L)
	Animal fat	(A)	266	125	163	high level(H)

<sup>a</sup> Experiment.

<sup>b</sup> Average analysed values.

<sup>c</sup> As  $\alpha$ -tocopherol (analysed values). In exp.2 in animal fat group 0.868 kg diet contains a same amount of vit. E as 1 kg diet in starch group.

In each batch, four sows from each diet were placed with their piglets in each of two climatic-respiration chambers (80 m<sup>3</sup> each) between days 14 and 27 of lactation. Energy and nitrogen balance were measured. Animals were housed individually in metabolic cages during their stay in the chambers (4 sows with their piglets per chamber).

#### *Energy- and Nitrogen Balance of Sows*

After 4 d of adaptation to the respiration chamber, nitrogen balances per sows and energy balances per chamber were determined over a 7 days collection period (between days 18 and 25 of lactation) according to Babinszky et al. (1991b).

#### *Measurement of Heat Production of Sows and Piglets*

During the balance period (7 days), two respiration measurements of 48 h and 72 h respectively were made in 9 continuous min intervals. Heat production (sows plus piglets per chamber) was determined indirectly by measurement of the CO<sub>2</sub> produced and the O<sub>2</sub> consumed (Verstegen et al., 1987). The heat production of sows [HP] was derived from the total heat production (sows plus piglets per chamber) by subtracting heat production of piglets. Heat production of piglets was computed by assuming efficiencies of milk metabolizable energy above maintenance into energy in piglets of 0.95 according to Jordan (1971). Daily maintenance requirement of piglets was assumed to be 450 kJ ME/kg<sup>0.75</sup> according to Verstegen et al. (1985).

Table 2. Major components of diets for lactating sows (Exp.1 and 2)

Composition g/kg	Experiment 1		Experiment 2	
	Diet 1 <sup>a</sup>	Diet 2 <sup>b</sup>	Diet 1 <sup>a</sup>	Diet 2 <sup>b</sup>
Hominy feed	77	150	-	-
Corn	103	30	-	-
Sunflower seed	85	36	-	-
Soya bean meal, solv.extr.	80	125	97	112
Soya bean, heat treated	68	29	-	-
Soya bean meal, toasted	-	-	48	55
Barley	-	-	56	65
Rapeseed meal	-	-	30	35
Sunflower meal	-	-	150	173
Wheat middlings	-	-	42	48
Peas	65	58	-	-
Tapioca meal	386	196	266	306
Corn starch	-	-	200	-
Animal fat	-	37	10	90
Vitamin-mineral premix <sup>c</sup>	7.5	7.5	5.0	5.8
Other components <sup>d</sup>	128.5	331.5	96.0	110.2
Nutrient content as analysed (g/kg DM)				
Crude protein	188	193	194	217
Crude fat	43	75	37	125
Starch	396	286	418	266
as calculated				
Netto energy for swine <sup>e</sup> , MJ/kg DM	10.0	10.0	10.1	11.6
Digestible lysine <sup>f</sup> , g/kg DM	7.44	7.44	7.56	8.70

<sup>a,b</sup> Both diets in both experiments contained low and high vitamin E level as stated in Table 1. In experiment 2 0.868 kg of Diet 2 contains the same amount of ingredients and nutrients apart from starch and fat content as 1 kg of Diet 1.

<sup>c</sup> 1 kg basal premix contains in exp.1: DL-alpha-tocopheryl acetate 2000 mg, selenium 27 mg. See also Babinszky et al.(1992).

In exp.2: DL-alpha-tocopheryl acetate 2400 mg, selenium 20 mg. See also Babinszky et al.(1991a).

<sup>d</sup> Exp.1: Details of other components have been reported by Babinszky et al. (1992). Exp.2: alfalfa meal, cane molasses, meat meal tankage, DL-methionine, DL-lysine, monocalcium phosphate, salt.

<sup>e</sup> According to the Rostock net energy system: Centraal Veevoederbureau (CVB,1988).

<sup>f</sup> Faecal digestibility (CVB, 1988).

### Calculations

**Respiratory Quotient [RQ].** The total RQ (sows plus piglets together) was calculated per chamber on the basis of the CO<sub>2</sub> produced and O<sub>2</sub> consumed (litre/kg<sup>0.75</sup>). The RQ of sows was derived from the

total CO<sub>2</sub> produced and O<sub>2</sub> consumed (sows plus piglets per chamber) by subtracting CO<sub>2</sub> produced and O<sub>2</sub> consumed by piglets. The CO<sub>2</sub> production and O<sub>2</sub> consumption of piglets (one value per chamber) were computed from heat production of piglets and by assuming a mean RQ for all piglets of 0.77 (van der Hel and Verstegen, 1987). This value is similar to 0.79 which was reported by Mount (1969) for suckling piglets of 3 days of age.

**Heat Production Due to Suckling.** Suckling occurred of litters within chamber was synchronized during night more than during day time. Therefore this period (app. from 1900 until 0700 h) was used for calculation. No difference in suckling frequency between day (app. from 0700 until 1900 h) and night was found. The calculation was made from data on total heat production of sows and piglets measured during 5 nights. HP was measured per chamber in 9 min intervals. Suckling occurrence was checked by monitoring the activity peaks in the chamber. Activity of animals was determined with ultrasound waves also in 9 minute intervals according to the method described by Verstegen et al. (1987). The calculation was done on the following way:

We chose 6 two hour periods during a night (from 1900 until 0700 h). The heat production data during subsequent 9 min periods within each two hours were somewhat arbitrarily grouped into different classes. A clear peak in 9 min heat production (HP during 9 min of more than 100 kJ/kg<sup>0.75</sup> above the mean in the 2 h period) and a clear peak in activity (during 9 min of more than double of the mean in 2 h period) was considered a "suckling bout" (HPs).

Moreover, we considered a "resting phase" for animals (basic level of heat production = HPb) to occur, if the HP was more than 50 kJ/kg<sup>0.75</sup> and the activity was less than 50% of the mean during that 2 h period. The remaining phases were considered "after suckling" and these were not used for calculation, because variation in heat production was then a mixture of activity and post-prandial heat production.

The HP (sows plus piglets) due to suckling was derived as follows:

$$\text{HPd} = \text{HPs} - \text{HPb}$$

where: HPd= heat production during suckling (sows plus piglets) above the basic level of HP (kJ/kg<sup>0.75</sup>, expressed per 24 h); HPs= heat production during suckling (sows plus piglets) including basic HP, "suckling bout" (kJ/kg<sup>0.75</sup>, expressed per 24 h); HPb= basic level of HP (sows plus piglets), "resting phase" (kJ/kg<sup>0.75</sup>, expressed per 24 h).

Mean values for HPs, HPb and HPd were calculated per 2-hour-period per chamber during 5 nights.

#### **Chamber Conditions**

Chamber conditions throughout the experiment were maintained at 18 °C air temperature, and 65% relative humidity. The light regimes in the chambers were 12 hrs L (light) - 12 hrs D (dark). Light

was on from 0700 until 1900. Heat lamps were used for piglets and placed at about 60 cm above the floor in each crate in the farrowing barn and in respiration chambers.

***Suckling frequency***

The suckling frequency was determined per chamber on the basis of HP and activity of sows and piglets measured app. from 1900 until 0700 h in two separate nights. During the measuring periods, the peaks in HP (sow plus piglets) were thought to be related to suckling. From the number of peak values (8 chambers and two measuring nights together) a mean value was calculated per experiment.

***Milk Production of Sows***

Milk production of sows was measured by weighing piglets before and after suckling at days 16, 21 and 26 of lactation. For the calculation of milk yield, corrections for weight loss of piglets due to metabolic rate, evaporation, urination and defecation during suckling were applied (Babinszky et al., 1992). The total milk production of sows during the balance period was estimated from the mean daily milk production of the three measurement days.

***Milk- and Feed Sampling***

Milk samples were obtained from sows and from all functional teats of sows at d 14 of lactation and at the end of lactation (27 d of lactation) using an injection of oxytocin, according to the method described by Babinszky et al. (1991a). Experimental diets were sampled for analysis of nutrient content twice each week.

***Weight of Sows and Piglets***

Sows and piglets were weighed individually at the start and end of the balance period (at days 18 and 25 respectively).

***Feed and Milk Analysis***

The nutrient content of diets (dry matter, crude protein, crude fat, starch) and the composition of milk (dry matter, protein, fat, and ash) was analysed as reported by Babinszky et al. (1991a, 1992). The lactose content of milk was calculated by subtracting fat, protein and ash from dry matter content. Gross energy content of feed was measured by bomb calorimetry (IKA C700T; IKA-Werk, Staufen, Germany). The energy content of milk was calculated on the basis of fat, protein and lactose content in the milk according to the formula of Klaver et al. (1981) as reported earlier by Babinszky et al. (1991b).

Alpha-tocopherol content in feed was analysed using the HPLC method (F. Hoffmann- La Roche Laboratory, Basle, Switzerland) according to Manz and Philipp (1981).

**Experiment 2 {Exp.2}****Animals**

A total of 32 first litter PIC hybrid sows were used in four subsequent batches of 8 animals each.

**Experimental Arrangement and Diets**

Two basal diets (low and high fat content diets) were used. In the low-fat content diet, the energy source was mainly starch [St]. In the high-fat content diet, 20% cornstarch was substituted for animal fat [A]. The animal fat was the same product as described in exp.1. Both basal diets contained low levels of vitamin E [L] (21 and 24 mg of  $\alpha$ -tocopherol /kg feed) and high level of vit. E [H] (140 and 163 mg of  $\alpha$ -tocopherol / kg diet, Table 1). The supplementation of vit. E was done with DL- $\alpha$ -tocopheryl acetate. The components of the basal diets can be seen in Table 2. In the high-fat diet, 0.868 kg of feed contained the same amounts of nutrients apart from fat and starch content, and a similar amount of  $\alpha$ -tocopherol as 1 kg of the low-fat diet. The animals in batches 1 and 4 received diets LSt or LA and in batches 2 and 3 the diets were HSt or HA. In each batch four animals were fed the same diet.

**Feeding**

During pregnancy, gilts were fed as described in experiment 1. The experiment started after farrowing and lasted until weaning (27 days of lactation). The sows received the experimental diets from one day after farrowing onwards. Daily feed ration of sows in the low-fat group was calculated as in experiment 1. In the high-fat group sows received the calculated amount of the diet multiplied by 0.868 in order to standardize on energy intake. Creep feed was not provided. After parturition, the litters were standardized to 9 piglets in all batches.

**Housing of Animals and Experimental Procedures**

Housing of animals and experimental procedures were the same as in exp.1. Data recording, measurements, calculations of heat production and respiratory quotient and feed and milk sampling were also identical to exp.1. Milk production of sows during balance per sow was calculated from d 16 and 26 of lactation.

**Statistical Analysis**

Data of both experiments were analysed by analysis of variance using GLM procedure (SAS,1990). Since no significant interaction between fat level and vitamin E level was found in either experiment, the following model was used:

$$Y_{ijkl} = \mu + A_i + B_j + C(B)_{k(j)} + e_{ijkl}$$

where:  $Y_{ijkl}$  = dependent variable;  $\mu$  = mean;  $A_i$  = fat level in sow's diet ( $i=1, 2$ );  $B_j$  = vit. E in sow's diet ( $j=1, 2$ );  $C(B)_{k(j)}$  = batch variation within vit. E levels ( $k(j)=1, 2, 3, 4$ ) and  $e_{ijkl}$  = residual error.

Details concerning statistical analysis have been given by Babinszky et al. (1991b). Since one value per chamber was calculated for all parameters, data on traits tested represent the mean of four observations per treatment. However, data on heat production due to suckling represents the mean of eight observations per experiment per measuring period.

## Results and Discussion

The results of both experiments are reported per fat level in the lactating sow's diet since no significant effects of vitamin E were found.

### *Daily Metabolizable Energy (ME) Intake of Sows and Piglets*

The daily ME intake of sows and piglets during the balance period are given in Table 3. The ME intake of sows in different treatments in exp.1 were similar. In exp. 2 the mean daily ME intake in low-fat group was somewhat higher than in the high-fat group ( $P < 0.05$ ).

**Table 3. Metabolizable energy (ME) intake of sows and piglets during balance period (between 18 and 25 days of lactation)**

Item	Experiment 1			Experiment 2		
	Energy source <sup>a</sup>		RMSE <sup>b</sup>	Energy source <sup>a</sup>		RMSE <sup>b</sup>
	St	A		St	A	
Daily ME intake						
Sows, kJ/kg <sup>0.75</sup>	1602	1626	18	1454 <sup>d</sup>	1404 <sup>e</sup>	16
Piglets, kJ/kg <sup>0.75</sup> <sup>c</sup>	1401	1404	59	1364	1496	83

<sup>a</sup> Treatments and codes are defined in Table 1.

<sup>b</sup> Root mean square error.

<sup>c</sup> ME from milk = 0.95 x milk energy (Jordan, 1971).

<sup>d,e</sup> Different superscripts in the same row indicate significant differences among treatment groups in exp.2 ( $P < 0.05$ ).

The ME intake of piglets from milk (milk energy x 0.95; according to Jordan, 1971) in exp.1 was not affected by fat level of the lactation diet. In exp.2 the ME intake in the high-fat group tended to be

higher than in the low-fat group. The difference however, was not significant. This somewhat higher ME intake of piglets was correlated to higher fat (energy) content of milk. The daily milk production was not affected by the difference in dietary fat levels (Babinszky et al., 1991c). The total metabolic weights of piglets during the balance period was 31.4 kg in the low, and 32.4 kg in the high fat group respectively (RMSE: 1.4 ;  $P > 0.38$ ). The elevated level of milk fat with the high dietary fat in the sows' diet was according to expectations. Other investigations also showed a similar response as reviewed by Moser and Lewis (1980), Pettigrew (1981) and Drochner (1989). Newcomb et al. (1991) also reported that after feeding starch or soybean oil or medium-chain triglyceride during late gestation (d 100 of pregnancy to parturition) the gross energy content in colostrum was increased with the non starch diets. The differences between starch and oil however, were not always significant.

#### ***Weight of Sows and Piglets***

Data on weight of sows and piglets can be seen in Table 4. Differences between treatment groups in both experiments with regard to liveweight of sows at the start and end of the balance and also the average weight during balance were not significant. It should be noted also that in exp.2 in the high-fat group, sows tended to loose more weight than in the low-fat group.

The mean weight of individual piglets in exp.1 at start and end of balance was higher in the moderate-fat group than in the low-fat group ( $P < 0.05$ ). The weight of piglets in exp. 2 were similar in both treatment groups. The data from literature with regard to effect of dietary fat in sow diet on piglets' weight are not consistent. Moser and Lewis (1980), showed in several experiments that dietary fat had only minor or no effect on the piglets weight at birth or at weaning. Pettigrew (1981) reviewed 16 trials (no creep feed during suckling). Nine trials showed positive effect on piglets' weight when fat was added to the sow's diet and 7 showed no or a small negative effect. He concluded that the piglet weight at weaning appears to increase if the concentration of dietary fat is at least 8 %. Coffey et al. (1982) and Nelssen et al. (1985) also found no clear effect on piglets weight when the sow's diet was supplemented with fat.

#### ***Respiratory Quotient [RQ] and Heat Production [HP]***

The respiratory quotients and heat production of sows and piglets are given in Table 5. In exp.1 both total RQ (sows plus piglets) and RQ of sows are lower in the moderate-fat group than in the low-fat group ( $P < 0.05$ ). In exp.2 a similar tendency was observed for total-RQ and sow-RQ. For animals fed a high-fat diet a lower RQ was calculated than for those fed a low-fat diet ( $P < 0.05$ ). The

**Table 4. Live weight of sows and piglets during balance period (between 18 and 25 days of lactation)**

Item	Experiment 1			Experiment 2		
	Energy source <sup>a</sup>		RMSE <sup>b</sup>	Energy source <sup>a</sup>		RMSE <sup>b</sup>
	St	A		St	A	
Weight of sow, kg						
balance start	162.7	161.4	3.3	158.1	157.0	2.2
balance end	161.3	160.9	3.7	155.7	152.7	1.8
avg. weight	162.0	161.1	3.5	156.9	154.9	1.8
Weight of piglets, kg						
balance start	4.91 <sup>c</sup>	5.15 <sup>d</sup>	0.10	4.64	4.74	0.28
balance end	6.56 <sup>c</sup>	6.84 <sup>d</sup>	0.10	6.17	6.47	0.31
avg. weight	5.75 <sup>c</sup>	6.01 <sup>d</sup>	0.08	5.41	5.61	0.29

<sup>a</sup> Treatments and codes are defined in Table 1.

<sup>b</sup> Root mean square error.

<sup>c,d</sup> Different superscripts in the same row indicate significant differences among treatment groups in exp.1 ( $P < 0.05$ ).

**Table 5. Effect of dietary fat level in the lactation diet on respiratory quotient (RQ) and on heat production of sows and piglets<sup>a</sup> between 18 and 25 days of lactation**

Item	Experiment 1			Experiment 2		
	Energy source <sup>b</sup>		RMSE <sup>c</sup>	Energy source <sup>b</sup>		RMSE <sup>c</sup>
	St	A		St	A	
RQ, sow+piglets	0.98 <sup>d</sup>	0.95 <sup>e</sup>	0.01	0.95 <sup>f</sup>	0.89 <sup>g</sup>	0.02
sow	1.10 <sup>d</sup>	1.07 <sup>e</sup>	0.01	1.06 <sup>f</sup>	0.96 <sup>g</sup>	0.03
Heat production						
total (sow+piglets)	711	700	12	695 <sup>f</sup>	674 <sup>g</sup>	6
sow	795	779	20	771 <sup>f</sup>	719 <sup>g</sup>	18
piglets	600	601	9	594	615	13

<sup>a</sup> Expressed as  $\text{kJ/kg}^{0.75}$  per 24 h.

<sup>b</sup> Treatments and codes are defined in Table 1.

<sup>c</sup> Root mean square error.

<sup>d,e</sup> Different superscripts in the same row indicate significant differences among treatment groups in exp.1 ( $P < 0.05$ ).

<sup>f,g</sup> Different superscripts in the same row indicate significant differences among treatment groups in exp.2 ( $P < 0.05$ ).

relatively high RQ for sows in both treatments in exp.1, and in the starch group in exp.2, indicates that milk fat is synthesized from carbohydrates (Brouwer, 1958).

Total HP (sows plus piglets) and HP of both sows and piglets, are given in Table 5. In exp.1 no treatment effect with regard to total HP and HP of sows or piglets was found. In exp.2 in the high fat group, both total HP and HP of sows were clearly lower than in the low-fat group ( $P < 0.05$ ). The higher HP of sows fed the starch diet (low-fat diet) meant a lower efficiency of utilization of metabolizable energy from the carbohydrate diet for milk, compared to that of the fat diet. According to van Es and Boekholt (1987) the efficiency of ME from glucose for fat deposition (and probably also for milk fat) has an efficiency of about 80 %. When ME from fat is used for fat their efficiency is about 95 % due to fewer conversion steps.

Müller and Kirchgessner (1980) did not find clear differences in HP, in mature non-pregnant sows fed a diet containing only protein and fat or fed a mixed diet (carbohydrate plus fat). In their trial, the respiratory quotient was also significantly lower for a high-fat diet compared to a mixed diet. Kirchgessner and Müller (1984) reported that in non-pregnant, non lactating sows, a high-fat diet fed around maintenance had no effect on diet-induced thermogenesis compared to a carbohydrate-rich diet.

Similarly Prabucki and Schürch (1977) found in rats fed at a low level of intake, that the ratio of carbohydrates to fat in isocaloric diets had no effect on heat production. Similarly to Müller and Kirchgessner (1980) they reported that the RQ decreased with increasing proportion of fat calories in the diet.

Yang and van Itallie (1976) reported that in obese humans the basal metabolic rates (Kcal/24h) were unaffected by the high fat diet compared to carbohydrate-rich diet.

Hillcoat and Annison (1974) on the other hand, noted that with growing pigs heat production tended to decrease with increasing dietary fat level. In our study we found a similar tendency for HP of sows. It should be noted however, that we found a much more pronounced fat effect on heat production of sows compared to Hillcoat and Annison (1974). In our investigation the daily ME intake ( $\text{kJ}/\text{kg}^{0.75}$ ) was higher. In the present study we used lactating animals at controlled ME intake, which have a higher fat intake compared to the literature data.

From the results of the present investigation it may be concluded that lactating sows fed a high level of dietary fat produce less heat, than those fed a carbohydrate rich (low-fat level) diet.

#### ***Heat Production Due to Suckling***

No treatment effects on heat production due to suckling was found. Therefore the results are presented by experiment (Table 6.). Data in both experiments show only a small variation in extra HP

(HPd) during the night (range in exp.1: from 230 to 264, in exp.2: from 214 to 252 kJ/kg<sup>0.75</sup> respectively). The average increase in heat production (HPd) expressed in 24 h, in exp.1 was 247 kJ/kg<sup>0.75</sup> and in exp.2 237 kJ/kg<sup>0.75</sup>.

**Table 6. Heat production of sows and piglets due to suckling<sup>a</sup> between 18 and 25 days of lactation (Mean ± s.e.)**

Periods, hours <sup>c</sup>	Experiment 1 <sup>b</sup>		Experiment 2 <sup>b</sup>	
	HPb	HPd	HPb	HPd
1900 - 2100	640±8	264±16	607±6	246±14
2100 - 2300	623±6	252±9	584±6	237±5
2300 - 0100	580±6	247±9	558±8	240±7
0100 - 0300	561±4	230±5	524±7	252±8
0300 - 0500	530±4	247±11	507±4	214±6
0500 - 0700	513±4	245±12	491±7	236±6
Overall mean <sup>d</sup>	575±7	247±4	545±6	237±4

<sup>a</sup> Expressed as kJ/kg<sup>0.75</sup> per 24 h.

<sup>b</sup> Codes are defined in text. In both experiments n= 8 per period.

<sup>c</sup> Duration of each period is two hours.

<sup>d</sup> In both experiments n= 48 per experiment (6 periods and 8 chambers means together).

The overall mean value of the increased heat production (sow plus piglets: HPd) of both experiments is 242 kJ/kg<sup>0.75</sup> [(247+237)/2]. We assumed that the combined duration of suckling and activity around suckling is about 4.5 min (den Hartog et al., 1984). We assumed furthermore, that the sows have an increase in HP equivalent to about 10% of their maintenance requirement (42 kJ/kg<sup>0.75</sup>d<sup>-1</sup>) during suckling. If the metabolic weight of sow and piglets are 44 kg and 32 kg respectively, the increase in HP of piglets alone expressed in a 24 h period, is calculated as

$$((242 \times 9/4.5) \times 76) - (42 \times 44)/32 = 1092 \text{ kJ/kg}^{0.75}.$$

This value indicates that the suckling itself requires about two times more energy than the mean level of daily heat production of piglets (600 kJ/kg<sup>0.75</sup>, Table 5).

### *Suckling frequency*

In the literature different data on suckling intervals are given. The values for suckling frequency range between 60 and 70 minutes and were mostly measured with 2 to 3 week old piglets (Mahan et al., 1971; Lewis et al., 1978; van der Steen, 1983; Speer and Cox, 1984; den Hartog et al., 1984).

Earlier studies have been reported with nearly similar intervals of 55-65 min at the same age of piglet (after Lewis et al., 1978; Shepperd, 1929; Niwa et al., 1951; Smith, 1952; Berge and Indrebo, 1953, Barber et al., 1955). These literature data were mostly based on counting of suckling in different trials and under different conditions. However, it may be concluded that the average suckling interval for 2 to 3 week old piglets is about 60 minutes.

In the present study, these observations were obtained by measuring peaks in heat production (sow plus piglets) between days 18 and 25 of lactation. The pattern of heat production of sows and piglets as measured between 1900 and 0700 h in one chamber is illustrated in Figure 1. This pattern was characteristic of both experiments. From this figure it can be seen that the number of HP-peaks during 12 h is about 13. The average suckling number during 12 hours in both experiments was 12.5 (range in Exp.1 :11-14 in Exp.2: 10-14). In both experiments a similar number of HP-peaks were found between the night and day period. We concluded that piglets suckle at about hourly intervals when they are 3 to 4 weeks of age. These data confirm the observations as reported in the literature.

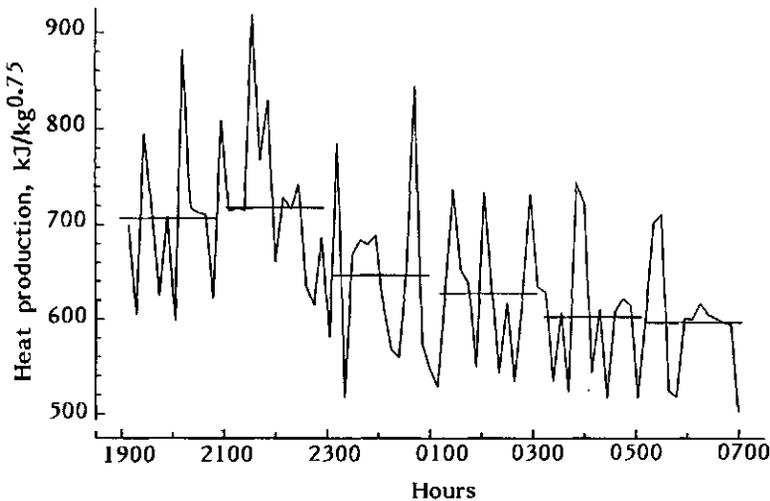


Figure 1. Heat production (sows plus piglets) from 1900 until 0700 h in one chamber (expressed as  $\text{kJ/kg}^{0.75}$  per 24 h). Horizontal line in every period indicates the mean heat production level during two hours.

*In conclusion*, it can be stated that feeding a lactation diet with a high level of fat causes sows to produce less heat ( $P < 0.05$ ). The respiratory quotient of sows fed a moderate or high fat level are lower ( $P < 0.05$ ) than those fed a low dietary fat (carbohydrate rich diet). Suckling frequency is about once per hour and it was not affected by the dietary fat level in the sow's diet. The extra energy requirement of suckling for piglets above the basic level of heat production was estimated as 1092 kJ/kg<sup>0.76</sup>. The dietary vitamin E level had no effect on traits tested.

### **Implications**

The present paper on different fat levels in the lactating sow's diet shows that sows being fed a high level of dietary fat produce less heat than those fed a carbohydrate rich (low-fat) diet. Low heat production in the lactating sow can be beneficial in conditions in which heat production is a burden on the animals, especially at high ambient temperatures. Moreover it may be beneficial by preventing a large decrease in feed intake by the sows in such conditions. The suckling itself requires about two times more energy than the mean level of daily heat production of piglets.

## References

- ARC. 1981. Agricultural Research Council. The Nutrient Requirements of Pigs. Commonwealth Agricultural Bureaux, Slough.
- Babinszky, L., D.J. Langhout, M.W.A. Verstegen, L.A. den Hartog, P. Joling, and M. Nieuwland. 1991a. Effect of  $\alpha$ -tocopherol and dietary fat source on some blood and immunological variables in lactating sows. *Anim. Prod.* **52**: 367-375.
- Babinszky, L., M.W.A. Verstegen, L.A. den Hartog, W. van der Hel, T. Zandstra, E.M.W. van den Elsen, and van J.T.P. Dam. 1991b. Effect of dietary fat level and vitamin E on energy- and nitrogen balances of primiparous lactating sows. *J. Anim. Sci.* (submitted for publication).
- Babinszky, L., M.W.A. Verstegen, L.A. den Hartog, T. Zandstra, P.L. van der Togt and J.T.P. van Dam. 1991c. Effect of dietary fat level in the lactation diet on the performance of primiparous sows and their piglets. *Anim. Prod.* (submitted for publication).
- Babinszky, L., D.J. Langhout, M.W.A. Verstegen, L.A. den Hartog, T. Zandstra, P.L.G. Bakker and J.A.A.M. Verstegen. 1992. Dietary vitamin E and fat source and lactating performance of primiparous sows and their piglets. *Livest. Prod. Sci.* **30**: 155-168.
- Boyd, R.D., B.D. Moser, E.R. Peo, Jr, A.J. Lewis and R.K. Johnson. 1982. Effect of tallow and choline chloride addition to the diet of sows on milk composition, milk yield and preweaning pig performance. *J. Anim. Sci.* **54**: 1-7.
- Britt, J.H. 1986. Improving sow productivity through management during gestation, lactation and after weaning. *J. Anim. Sci.* **63**: 1288-1296.
- Brouwer, E. 1958. On simple formulae for calculating the heat expenditure and the quantities of carbohydrate and fat metabolized in ruminants, from data on gaseous exchange and urine-N. In: G. Thorbek and H. Aersøe (Eds) 1. Symposium on Energy Metabolism. Proc. pp. 182-192. EAAP Publication No. 8. Statens Husdyrbrugsudvalg, Copenhagen, Denmark.
- Coffey, M.T., R.W. Seerley and J.W. Mabry, J.W. 1982. The effect of supplemental dietary energy on sow milk yield, milk composition and litter performance. *J. Anim. Sci.* **55**: 1388-1394.
- CVB. 1988. Dutch Feeding Tables [in Dutch]. Centraal Veevoederbureau, The Netherlands.
- Drochner, W. 1989. Einflüsse von Fettzulagen an Sauen auf Aufzuchtleistungen und Fruchtbarkeit [in German]. *Übers. Tierernährg.* **17**: 99-138.
- Es, A.J.H. van and H.A. Boekholt. 1987. Energy metabolism of farm animals. In: M.W.A. Verstegen and A.M. Henken (Eds) Energy Metabolism in Farm Animals. pp.3-19. Martinus Nijhoff Publishers, Dordrecht.
- Hartog, L.A. den, M.W.A. Verstegen, H.A.T.M. Hermans, G.J. Noordewier and G.J.M. van Kempen. 1984. Some factors associated with determination of milk production in sows by weighing of piglets. *J. Anim. Physiol. a. Anim. Nutr.* **51**: 148-157.
- Hel, W. van der, M.W.A. Verstegen. 1987. Metabolic rate of piglets between sucklings. In: M.W.A. Verstegen and A.M. Henken (Eds) Energy Metabolism in Farm Animals. pp.63-69. Martinus Nijhoff Publishers, Dordrecht.
- Hillcoat, J.B. and E.F. Annon. 1974. The efficiency of utilisation of diets containing maize oil, tallow and tallow acid oil in the pig. In: K.H. Menke, H.J. Lantzsich and J.R. Reichl (Eds) Energy Metabolism of Farm Animals. pp. 177-180. EAAP Publications, Publication No. 14. Universität Hohenheim, Germany.
- Jordan, J.W. 1971. Investigations into energy metabolism of bacon pigs and piglets. *Agr. Progress* **46**: 9-25.
- Kirchgeßner, M. and H.L. Müller. 1984. Thermogenese bei Verabreichung einer ketogene Diät im Modellversuch an Sauen [in German]. *Int. J. Vitam. Nutr. Res.* **54**: 99-106.
- Klaver, J., G.J.M. van Kempen, P.G.B. de Lange, M.W.A. Verstegen, and H. Boer. 1981. Milk composition and daily yield of different milk components as affected by sow condition and lactation/feeding regimen. *J. Anim. Sci.* **52**: 1091-1097.

- Lewis, A.J., V.C. Speer and D.G. Haught. 1978. Relationship between yield and composition of sows' milk and weight gains of nursing pigs. *J. Anim. Sci.* **47**: 634-638.
- Mahan, D.C., D.E. Becker, H.W. Norton and A.H. Jensen. 1971. Milk production in lactating sows and time lengths used in evaluating milk production estimates. *J. Anim. Sci.* **33**: 35-37.
- Manz, U. and K. Philipp. 1981. A method for the routine determination of tocopherols in animal feed and human foodstuffs with the aid of high performance liquid chromatography. *Int. J. Vitam. Nutr. Res.* **51**: 342-348.
- Moser, B.D. and A.J. Lewis. 1980. Adding fat to sow diets - An update. *Feedstuffs* **52**: 36-38.
- Mount, L.E. 1969. The respiratory quotient in the newborn pig. *Br. J. Nutr.* **23**: 407-413.
- Müller, H.L. and M. Kirchgessner. 1980. Energy utilization of a carbohydrate-free protein-fat diet by sows. In: L.E. Mount (Ed) *Energy Metabolism*. pp. 249-252. EAAP Publication, Publication No. 26. Butterworths, London.
- Nelssen, J.L., A.J. Lewis, E.R. Peo, Jr and B.D. Moser. 1985. Effect of source of dietary energy and energy restriction during lactation on sow and litter performance. *J. Anim. Sci.* **60**: 171-178.
- Newcomb, M.D., D.L. Harmon, J.L. Nelssen, A.J. Thulin and G.L. Alee. 1991. Effect of energy source fed to sows during late gestation on neonatal blood metabolite homeostasis, energy stores and composition. *J. Anim. Sci.* **69**: 230-236.
- Pettigrew, Jr, J.E. 1981. Supplemental dietary fat for peripartal sows: A review. *J. Anim. Sci.* **53**: 107-117.
- Prabucki, A.L. and A. Schürch. 1977. The heat production of rats fed isocaloric and protein-equivalent diets with different proportions of fat to carbohydrates. *Bibl. Nutr. Dieta* (Basle) **25**: 78-82.
- SAS. 1990. SAS User's Guide: Statistics. SAS Inst., Inc., Cary, NC.
- Speer, V.C. and D.F. Cox, D.F. 1984. Estimating milk yield of sows. *J. Anim. Sci.* **59**: 1281-1285.
- Steen, H.A.M. van der. 1983. Maternal and genetic influences on production and reproduction traits in pigs. Ph.D. Thesis. Agricultural University Wageningen: 112 pp.
- Verstegen, M.W.A., J. Mesu, G.J.M. van Kempen and C. Geerse. 1985. Energy balances of lactating sows in relation to feeding level and stage of lactation. *J. Anim. Sci.* **60**: 731-740.
- Verstegen, M.W.A., W. van der Hel, H.A. Brandsma, A.M. Henken and A.M. Bransen. 1987. The Wageningen respiration unit for animal production research: a description of the equipment and its possibilities. In: M.W.A. Verstegen and A.M. Henken (Eds) *Energy Metabolism in Farm Animals*. pp. 21-48. Martinus Nijhoff Publishers, Dordrecht.
- Yang, M.U. and T.B. van Itallie. 1976. Metabolic responses of obese subjects to starvation and low-calorie ketogenic and nonketogenic diets. *J. Clin. Invest.* **58**: 722-730.

## Chapter 3

**Effect of dietary fat level in the lactation diet on the performance of primiparous sows and their piglets**

L. Babinsky<sup>1,3</sup>, M. W. A. Verstegen<sup>1</sup>, L. A. den Hartog<sup>2</sup>, T. Zandstra<sup>1</sup>, P. L. van der Togt<sup>1</sup> and J. T. P. van Dam<sup>1</sup>

<sup>1</sup> Department of Animal Nutrition, Agricultural University Wageningen, Haagsteeg 4, 6708 PM Wageningen, The Netherlands

<sup>2</sup> Research Institute for Pig Husbandry, P.O.Box 83, 5240 AB Rosmalen, The Netherlands

<sup>3</sup> Research Institute for Animal Nutrition, H-2053 Herceghalom, Hungary

Submitted for publication: Animal Production

## Effect of dietary fat level in the lactation diet on the performance of primiparous sows and their piglets

### Abstract

A total of 63 primiparous hybrid sows were used in two experiments to study the effect of different fat and vitamin E levels in the lactation diet on the performance and milk production of sows and on the performance of piglets during suckling. In experiment 1 the major difference in energy sources in the lactation diets were tapioca starch or animal fat. 15 sows received the low fat level diet (starch and fat content: 396 and 43 g per kg DM) and 16 sows were fed moderate fat level diet (starch and fat content: 286 and 75 g per kg DM) during 4 weeks of lactation. In experiment 2, cornstarch (200 g/kg) was substituted by animal fat. 16 sows were fed during 4 weeks of lactation a low-fat diet (starch and fat content: 418 and 37 g/kg DM) and 16 were fed a high-fat diet (starch and fat content: 266 and 125 g/kg DM). Vitamin E contents of feeds in experiment 1 were 14 and 126 mg /kg diet, in experiment 2: 22 and 151 mg /kg diet. The live weight, backfat thickness and the milk production of sows were not affected by the different dietary fat levels. The high dietary fat increased the dry matter, fat and energy content of milk and the daily gain of piglets in the second part of lactation ( $P < 0.05$ ). The correlation between piglets gain and milk fat and milk energy intake ( $r$ ) in exp.1 were: 0.57 and 0.66; in exp.2: 0.41 and 0.40. The utilization of whole milk and dry matter, fat, protein and energy content of milk for piglet growth was not influenced by the dietary fat levels. Varying the level of dietary vitamin E did not affect the traits tested.

**Key Words:** sow, piglet, dietary fat, starch, lactation performance.

### Introduction

Many workers have shown that the addition of fat to the diets of sows during late gestation and(or) lactation increases milk production and fat content of colostrum and milk (Pettigrew, 1981). Results from some other investigations indicated an improved survival of piglets by feeding fat to sows before farrowing (Moser and Lewis, 1980; Pettigrew, 1981; Drochner, 1989). Most experimenters have used fat levels between 75 and 150 g/kg diet. This range gave the best results for survival (Moser and Lewis, 1980). The addition of fat to the sow's diet could be important for primiparous sows because they may have less lactation body reserve to produce milk, than multiparous sows. Other experiments have shown that the addition of fat to the sow's diet does not improve significantly litter performance during lactation when sows are fed at a restricted level (Nelssen et. al., 1985) or ad libitum (Boyd et al., 1982).

It has been suggested that increasing the polyunsaturated fatty acid (PUFA) content of the diet, increases the requirement for vitamin E (Pharazyn et al., 1990). Moreover several investigations suggested that vitamin E may increase the sow and litter performance (Adams and Zimmerman, 1982; Chavez and Patton, 1986).

In the literature hardly any systematic examinations have been carried out with regard to specified levels and amounts of dietary fat and vitamin E in the sow's diet.

The objective of the present study was to determine the effect of different levels of fat in combination with two vitamin E levels in the lactation diet on the performance and milk production of primiparous sows and on the performance of suckling piglets.

## Materials and Methods

### *Experiment 1 [exp.1]*

**Animals.** Thirty-two first litter PIC hybrid (Pig Improvement Company, England) sows were assigned to four subsequent batches of 8 animals each. Gilts were all bred at seven months of age. One animal had to be removed from the experiment at day 14 of lactation.

**Experimental arrangement and diets.** In two basal diets the major difference in energy sources were tapioca starch (low fat diet: St1) or animal fat (moderate fat diet: A1). The animal fat was slaughtering waste, packing house by-product (Nederlandse Thermo-Chemische Fabrieken, The Netherlands). In the animal fat the ratio between unsaturated and saturated fatty acids was 1.3. In the basal diet a low level [L] of vitamin E [vit. E]: 13 and 16 mg of  $\alpha$ -tocopherol per kg food respectively were included. In the high vit. E level diets [H] these were supplemented with DL- $\alpha$ -tocopheryl acetate upto 117 and 135 mg  $\alpha$ -tocopherol per kg food respectively (Table 1.). The experimental scheme was as follows (Scheme 1):

Batch	Number of animals (Diet)	
1	3 (LSt1)	4 (LA1)
2	4 (HSt1)	4 (HA1)
3	4 (HSt1)	4 (HA1)
4	4 (LSt1)	4 (LA1)

Where: L= low level of vitamin E and H= high level of vitamin E (Table 1).

**Feeding and housing.** During pregnancy gilts were all fed the same diet at a level of about 1.2 times maintenance (2.4 kg food per day per gilt). The components of the pregnancy diet was based on

mainly maize, soya bean meal (sol. extr.) tapioca meal and wheat. The diet contained 9.14 MJ NE, 180 g of crude protein and 15 mg of vit.E per kg food.

**Table 1. Experimental arrangements**

Exp. <sup>a</sup>	Treatment (Code)			
	Energy source in sows' diet	In sows' diet (g/kg DM) <sup>b</sup>		In sows' diet (mg/kg diet) <sup>c</sup>
		Starch	Fat	Vit.E
1	Tapioca starch (St1)	396	43	13 low level (L)
	Tapioca starch (St1)	396	43	117 high level(H)
	Animal fat (A1)	286	75	16 low level (L)
	Animal fat (A1)	286	75	135 high level(H)
2	Cornstarch (St2)	418	37	21 low level (L)
	Cornstarch (St2)	418	37	140 high level(H)
	Animal fat (A2)	266	125	24 low level (L)
	Animal fat (A2)	266	125	163 high level(H)

<sup>a</sup> Experiment.

<sup>b</sup> Average analysed values.

<sup>c</sup> As  $\alpha$ -tocopherol (analysed values).

The experiment started after farrowing and lasted until weaning at 27 days of lactation. Sows received the experimental diets during lactation from one day after farrowing onwards. During lactation each sow was fed maintenance food and in addition 0.4 kg feed per piglet (Babinszky, L., Verstegen, M.W.A and den Hartog, L.A., unpublished data). The main composition of the lactation diets is given in Table 2. Piglets had no access to creep feed during suckling. Litter size after farrowing was standardized to 10 piglets in batch 1 and to 9 piglets in batches 2, 3 and 4. On day 110 of gestation each gilt was moved to a farrowing barn and placed in a farrowing crate until day 13 of lactation. Between 14 and 27 days of lactation (weaning) 4 sows on the same diet with their piglets were assigned to a climatic-respiration chamber. Between 18 and 25 days of lactation energy- and nitrogen balances of sows were measured. The 4 sows on the other diet were assigned to an identical climatic-respiration chamber. In the respiration chambers the sows were housed individually with their piglets in metabolic cages. Description of the chambers is given elsewhere (Verstegen et al., 1987). Water was available ad libitum for both the sows and piglets during the experiment.

**Milk production of sows.** Milk production of sows was measured by weighing litters before and after suckling at days 6, 11, 16, 21 and 26 of lactation. The milk production of sows per suckling was

Table 2. Major components of diets for lactating sows (Exp.1 and 2)

Composition g/kg	Experiment 1		Experiment 2	
	Diet St1 <sup>a</sup>	Diet A1 <sup>b</sup>	Diet St2 <sup>a</sup>	Diet A2 <sup>b</sup>
Hominy feed	77	150	-	-
Corn	103	30	-	-
Sunflower seed	85	36	-	-
Soya bean meal, solv.extr.	80	125	97	112
Soya bean, heat treated	68	29	-	-
Soya bean meal, toasted	-	-	48	55
Barley	-	-	56	65
Rapeseed meal	-	-	30	35
Sunflower meal	-	-	150	173
Wheat middlings	-	-	42	48
Peas	65	58	-	-
Tapioca meal	386	196	266	306
Cornstarch	-	-	200	-
Animal fat	-	37	10	90
Vitamin-mineral premix <sup>c</sup>	7.5	7.5	5.0	5.8
Other components <sup>d</sup>	128.5	331.5	96.0	110.2

## Nutrient content

## as analysed (g/kg DM)

Crude protein	188	193	194	217
Crude fat	43	75	37	125
Starch	396	286	418	266
as calculated				
Netto energy for swine <sup>e</sup> ,				
MJ/kg DM	10.0	10.0	10.1	11.6
Digestible lysine <sup>f</sup> ,				
g/kg DM	7.44	7.44	7.56	8.70

<sup>a,b</sup> Both diets in both experiments contained low and high vitamin E level as stated in Table 1. In experiment 2 0.868 kg of Diet A2 contains the same amount of ingredients and nutrients (apart from starch and fat content) as 1 kg of Diet St2.

<sup>c</sup> 1 kg basal premix contains in exp.1: DL-alpha-tocopheryl acetate 2000 mg, selenium 27 mg. See also Babinszky et al.(1992).

In exp.2: DL-alpha-tocopheryl acetate 2400 mg, selenium 20 mg. See also Babinszky et al.(1991).

<sup>d</sup> Exp.1: Details of other components have been reported by Babinszky et al. (1992). Exp.2: alfalfa meal, cane molasses, meat meal tankage, DL-methionine, DL-lysine, monocalcium phosphate, salt.

<sup>e</sup> According to the Rostock net energy system: Centraal Veevoederbureau (CVB,1988).

<sup>f</sup> Faecal digestibility (CVB, 1988).

obtained from 5 to 6 subsequent measurements at one hour intervals on one measuring day.

Multiplying mean milk production per suckling by 24 gave the daily milk production (den Hartog et al., 1984). For the calculation of milk yield corrections for weight loss of piglets due to metabolic rate, evaporations, urinations and defaecations during suckling were used (Babinszky et al., 1992).

**Milk- and food sampling.** Milk samples were obtained at day 14 of lactation and also at weaning (27 days of lactation). An intravenous injection of oxytocin was used to obtain milk let down according to the method described by Babinszky et al. (1991). Experimental diets were sampled for analysis of nutrient and  $\alpha$ -tocopherol content twice each week.

**Weight and backfat thickness of sows.** Sows were weighed individually after farrowing and at weaning. The backfat thickness of sows was measured ultrasonically after farrowing and also at weaning according to Kroeske et al. (1968). An average of four measurements per animal was used as a mean backfat thickness.

**Weight of piglets.** The weight of piglets was measured just after birth, at standardization of litter size (day 2), at days 18 and 25 of lactation and at weaning.

**Milk and food analysis.** The nutrient content of diets (dry matter, crude protein, crude fat, starch) and the composition of milk (dry matter, protein, fat and ash) were analysed as reported earlier (Babinszky et al. 1991, 1992). Lactose content of milk was calculated by subtracting fat, protein and ash from dry matter content. Energy content of milk was calculated from fat, protein and lactose content according to Klaver et al. (1981). Energy content of 12 milk samples was also measured by bomb calorimetry in both experiments. We found a correlation ( $R^2$ ) of 0.98 (exp.1) and 0.99 (exp.2) between calculated and measured values (Babinszky et al., 1992).

Alpha-tocopherol content in feed was analysed by the high performance liquid chromatography (HPLC) method in Hoffmann- La Roche Laboratory (Basle, Switzerland) as described by Manz and Philipp (1981).

### **Experiment 2 [exp.2]**

**Animals.** A total of 32 first litter PIC hybrid gilts were used in four batches of 8 animals each.

**Experimental arrangement and diets.** Two basal diets with low and high fat content were used. In the low fat diet [St2] the energy source was mainly starch. In the high fat diet [A2] cornstarch (200 g per kg food) was substituted by animal fat. The animal fat was similar to that described in exp.1. Both basal diets contained low level of vit. E [L] (21 and 24 mg  $\alpha$ -tocopherol per kg food). These vit. E levels were supplemented with DL- $\alpha$ -tocopheryl acetate to give high levels of vit. E [H] (140 and 163 mg of  $\alpha$ -tocopherol per kg food; Table 1.). The composition of the basal diets is given in Table 2. The high fat diet was not diluted with crude fibre or other material. Therefore in the high fat diet

0.868 kg contained the same amounts of nutrients apart from fat and starch content and also a similar amount of  $\alpha$ -tocopherol as 1 kg of low fat diet. The experimental arrangement was similar to that described in exp.1 (Scheme 1), but in each batch four animals received the same diet.

**Feeding.** During pregnancy gilts were fed as described in exp.1. The experiment started after farrowing and lasted until weaning. Sows received the experimental diets from one day after farrowing onwards. Piglets were weaned at 27 days of lactation. The daily food ration of sows in the low fat group was calculated in the same way as in exp.1, in the high fat group sows received 0.868 of the calculated amount. In the high fat group sows received a similar total amount of dietary energy and nutrients as in the low fat group. Creep food was not provided during suckling. After farrowing, the litters were standardized to 9 piglets in all batches.

**Housing of animals and experimental procedures.** Housing of animals and the experimental procedures (measurements, data recording, calculations) were the same as in exp.1. Analyses of food and milk samples were identical as in exp.1. The milk production of sows was measured at days 6, 11, 16, 21 and 26 of lactation by a method similar to that described in exp. 1. With some sows the measurement of milk production at day 21 failed, therefore the average daily milk yield for the balance period was calculated from milk production on days 16 and 26 only.

#### **Calculations and statistical analysis**

**Correlation between milk nutrients output and piglets growth.** The relationship between dry matter, fat and energy output in sow's milk and daily gain of piglets in both experiments was estimated by using GLM procedure from the Statistical Analysis Systems Institute (SAS, 1990). The daily output per litter of dry matter or fat (g per day per piglet) or energy (kJ per day per piglet) in sow's milk was correlated to the daily gain of piglet (g). The daily gain of piglets (mean value per litter) was computed from piglet weight on days 18 and 25. Average daily milk production was calculated from the milk yield on days 16, 21 and 26 (in exp.1) or on days 16 and 26 (in exp.2). Average milk composition was determined from composition measured on days 14 and 27.

**Statistical analysis.** Data of both experiments were analysed in the following way:

Since only one vit. E level was used in each batch, the effect of energy source has been tested directly. This means that part of the variation between batches was related to vit. E level in the sow's diet. Therefore the batches were nested within vit. E level, permitting examination of the vit. E effect against the batch variation within vit. E levels. In both experiments interaction between energy source and vit. E level was not found. The following model was used:

$$Y_{ijkl} = \mu + A_i + B_j + C(B)_{k(j)} + e_{ijkl}$$

where:  $Y_{ijkl}$  = dependent variable;  $\mu$  = mean;  $A_i$  = type of energy source in sow's diet ( $i = 1, 2$ );  $B_j$  = vit. E level in sow's diet ( $j = 1, 2$ );  $C(B)_{k(j)}$  = batch variation within vit. E levels ( $k(j) = 1, 2, 3, 4$ );  $e_{ijkl}$  = residual error.

Data from both experiments were analysed by analysis of variance using GLM procedure of the SAS-package (SAS, 1990).

## Results and Discussion

The results of both experiments are given according to the energy source in lactating sow's diet only because no significant effect of dietary vit. E on measured traits was found.

**The daily nutrient intake of sows.** The daily mean nutrient intakes of the sows (metabolizable energy, digestible protein, digestible fat and starch) between days 18 and 25 of lactation are given in Table 3. Data in this table show that in both experiments the metabolizable energy and the digestible protein intakes were very similar for both the starch and the fat based diets. However, the digestible fat and starch intakes were different between these groups. The contrast in digestible fat intake in exp. 2 was, as expected, larger than in exp.1.

**Table 3. Mean daily metabolizable energy (ME), digestible protein, fat and starch intake of sows between days 18 and 25 of lactation**

Item	Experiment 1		Experiment 2	
	St1 <sup>a</sup>	A1	St2	A2
Daily nutrient intake				
ME, MJ/sow	72.7	73.3	64.4	61.6
ME, kJ/kg <sup>0.75</sup>	1605	1626	1454	1404
Dig. protein, g/sow	730	713	693	696
Dig. fat <sup>b</sup> , g/sow	169	295	125	400
Dig. starch <sup>c</sup> , g/sow	2015	1424	1835	1040

<sup>a</sup> Treatments and codes are defined in Table 1.

<sup>b</sup> From digestibility values determined by Babinszky, L. and M.W.A. Verstegen (unpublished data).

<sup>c</sup> Assuming digestibility of starch is 100% in the small intestine.

**Weight and backfat thickness of sows.** Data on weight and backfat thickness of sows are presented in Table 4. Live weight and backfat thickness of sows at the end of lactation were not significantly affected by the different fat levels in the diet. Schoenherr et al. (1989) found that sow weight change during a 22-day-lactation period was not affected by diets containing starch or fat both in a thermoneutral (20 °C) or in a hot (32 °C) environment. It should be noted that in contrast to our

experiment their animals were fed ad libitum and the fat supplemented diets resulted in a somewhat higher ME intake than the control diet. Nelssen et al. (1985) reported that sows fed a diet with tallow from late gestation throughout 4 weeks of lactation lost more weight ( $P < 0.05$ ) and tended to lose more backfat during lactation than animals fed a diet with cornstarch. They concluded that the short adaptation period (6 days) to the diet containing animal fat may have impaired digestion of the fat. This lower digestion of animal fat may increase the lactation weight and backfat losses. In our study

**Table 4. Live weight and backfat thickness of sows during lactation**

Item	Experiment 1			Experiment 2		
	St1 <sup>a</sup>	A1	RMSE <sup>b</sup>	St2	A2	RMSE
n (sows)	15	16		16	16	
Live weight, kg						
After farrowing	167.7	168.7	17.8	170.2	169.2	9.9
At weaning	159.6	158.3	18.4	150.8	147.1	8.0
Backfat thickness, mm						
After farrowing	18.9	17.9	3.5	17.5	17.8	3.3
At weaning	15.3	14.0	2.8	13.4	13.1	2.4

<sup>a</sup> Treatments and codes are defined in Table 1.

<sup>b</sup> Root mean square error.

in exp.2, however, the digestibility of fat in the high fat group was higher than in the low fat group (St2: 76.9%, A2: 81.8%; Babinszky, L. and Verstegen, M.W.A., unpublished data). This indicates that in our study the weight loss in sows fed the high dietary fat level in exp. 2 was not related to a lowered digestibility of fat.

**Milk composition.** The composition of milk is given in Table 5. In exp.1 the dry matter, protein, fat and energy (GE) content of milk on days 14 and 27 of lactation were not affected by diets. In exp. 2 on both days (14 and 27) dry matter, fat and energy content of milk from sows fed high dietary fat levels were significantly increased ( $P < 0.05$ ).

The elevated level of milk fat with the high dietary fat in the sow's diet was expected since other workers had observed a similar response (Moser and Lewis, 1980; Pettigrew, 1981). In the study of Boyd et al. (1982) 12 crossbred, third parity sows were fed control or tallow supplemented diets each with 770 mg/kg added choline chloride from day 100 of gestation until day 20 of lactation. They found that sows receiving added dietary fat (tallow) maintained a higher concentration of milk solids (not significant) and fat ( $P < 0.01$ ) throughout the lactation period than control sows. Milk protein

content was not influenced by the treatments. Coffey et al. (1982) also reported that feeding fat to sows throughout lactation increased the proportion of total lipids in milk ( $P < 0.05$ ).

Nelssen et al. (1985) concluded from their study that feeding animal fat resulted in an increased lipid content in the milk. At a restricted energy intake during lactation the extra energy in the milk may also result in extra lactation weight losses of the sows. Results of our study in the high fat group (exp.2) and the data from various experiments in the literature show that high levels of dietary fat can increase the dry matter, fat and energy content in milk. However, this was not seen in exp. 1 where the difference in dietary fat intake was much smaller between treatments.

**Table 5. Composition of milk at 14 and 27 days of lactation**

Item	Experiment 1			Experiment 2		
	St1 <sup>a</sup>	A1	RMSE <sup>b</sup>	St2	A2	RMSE
<b>Day 14:</b>						
n (sows)	13	16		16	16	
Dry matter, g/kg	198	201	17	201 <sup>c</sup>	215 <sup>d</sup>	17
Protein, g/kg	51	51	4	52	52	3
Fat, g/kg	88	91	17	90 <sup>c</sup>	105 <sup>d</sup>	17
Energy, kJ/g	5.47	5.58	0.66	5.58 <sup>c</sup>	6.14 <sup>d</sup>	0.67
<b>Day 27:</b>						
n (sows)	15	14		16	16	
Dry matter, g/kg	189	194	11	195 <sup>c</sup>	210 <sup>d</sup>	12
Protein, g/kg	51	52	4	56	57	4
Fat, g/kg	79	80	10	80 <sup>c</sup>	96 <sup>d</sup>	12
Energy, kJ/g	5.12	5.21	0.40	5.26 <sup>c</sup>	5.88 <sup>d</sup>	0.48

<sup>a</sup> Treatments and codes are defined in Table 1.

<sup>b</sup> Root mean square error.

<sup>c,d</sup> Different superscripts in the same line indicate significant differences among energy groups in exp.2 ( $P < 0.05$ ).

**Milk production of sows.** Data on milk production (least square means) can be seen in Table 6. The daily milk yield (kg milk per day per piglet) in exp.1 and in exp.2 was not influenced by the different dietary fat levels.

In various reported studies milk production of sows was measured on different days. Also different techniques were used during lactation when sows were fed diets with added fat. Lellis and Speer (1983) found no effects of 150 g supplemental tallow /kg on milk yield compared to a diet with 270 g supplemented dextrose /kg. However, data from other studies (Pettigrew, 1981; Boyd et al., 1982; Coffey et al., 1982; Shurson et al., 1986) show that milk yield might be increased with fat

supplementation. However, the enhancement of milk production was not always significant. It should be noted that in our study sows received the experimental diet for a period of 4 weeks.

**Table 6. Daily milk production (kg milk per piglet; least square means)**

Day of lactation	Experiment 1			Experiment 2		
	St1 <sup>a</sup>	A1	RMSE <sup>b</sup>	St2	A2	RMSE
6	0.64	0.59	0.11	0.59	0.62	0.11
11	0.86	0.83	0.15	0.82	0.79	0.13
16	0.90	0.90	0.16	0.85	0.91	0.15
21	1.00	1.06	0.14	0.97	0.99	0.16
26	1.04	1.08	0.17	1.01	0.98	0.13

<sup>a</sup> Treatments and codes are defined in Table 1.

<sup>b</sup> Root mean square error.

**Weight of piglets.** Live weight and daily gain of piglets were not influenced by an increase in fat level in the sow's diet in exp.1 (Table 7.). In exp.2 the weight of piglets was similar in both treatment groups. However, the daily gain of piglets in the second part of lactation (between 18 and 25 days of lactation) was higher ( $P < 0.05$ ) for piglets from sows fed the high dietary fat level in exp. 2.

**Table 7. Live weight of piglets during suckling**

Item	Experiment 1			Experiment 2		
	St1 <sup>a</sup>	A1	RMSE <sup>b</sup>	St2	A2	RMSE
n (litters)	15	16		16	16	
Piglet weight, kg						
at standardization	1.55	1.77	0.24	1.49	1.51	0.25
at day 18	4.94	5.20	0.69	4.64	4.74	0.57
at day 25	6.57	6.87	0.85	6.16	6.47	0.73
Daily gain/piglet, g during balance <sup>c</sup>	232	239	40	217 <sup>d</sup>	247 <sup>e</sup>	39

<sup>a</sup> Treatments and codes are defined in Table 1.

<sup>b</sup> Root mean square error.

<sup>c</sup> Between days 18 and 25 of lactation.

<sup>d,e</sup> Different superscripts in the same line indicate significant differences among energy groups in exp.2 ( $P < 0.05$ ).

Moser and Lewis (1980) concluded from results of several studies that over-all, dietary fat had only a minor or no effect on piglet weight at either birth or weaning. Pettigrew (1981) reviewed 16

supplementation trials (no creep food during suckling) in which 9 trials showed positive effect on weaning weight of piglets when fat was added to sow's diet and 7 showed no or a small negative effect. It was concluded that the mean piglet weight at weaning appears to increase if the dietary fat concentration is at least 80 g/kg. Coffey et al. (1982) and Nelssen et al. (1985), however, found that there was no significant difference in average piglet weight during the suckling period if the sow's diet was supplemented with fat.

Data from exp.2 in our study show a similar tendency to that concluded by Pettigrew (1981) i.e. that high levels of dietary fat in the lactating sow's diet may increase the daily gain of piglets especially in the second part of lactation.

*The utilization of whole milk and milk components.* Data in Table 8. show that in exp.1 the ratio of gain to whole milk and dry matter, fat, protein and energy content of milk was not significantly affected by the different levels of dietary fat in the lactation diet. In exp.2 piglets from the high fat group showed a lower ratio of gain for whole milk, dry matter and energy but this was not significant.

**Table 8.** The utilization of whole milk, milk components and milk energy for piglet growth between 18 and 25 days of lactation

Item	Experiment 1			Experiment 2		
	St1 <sup>a</sup>	A1	RMSE <sup>b</sup>	St2	A2	RMSE
n (litters)	13	14		16	16	
Whole milk, g/g gain/d	4.33	4.19	0.72	4.49	3.96	1.06
Dry matter, g/g gain/d	0.84	0.83	0.14	0.89	0.84	0.21
Fat, g/g gain/d	0.36	0.36	0.07	0.38	0.40	0.09
Protein, g/g gain/d	0.22	0.21	0.04	0.24	0.22	0.06
Energy, kJ/g gain/d	22.90	22.68	4.09	24.34	23.76	5.78

<sup>a</sup> Treatments and codes are defined in Table 1.

<sup>b</sup> Root mean square error.

The variation in the mean of these values was higher in exp.2 than exp.1, which may explain why the utilization of milk components is not significantly different. In the present study the mean efficiency of utilization of milk to gain ranged between 3.96 to 4.49 g of milk per g of pig gain (Table 8.). This value is similar to that reported by Lewis et al. (1978). They found a mean utilization of milk to piglet gain of 4.5 g milk per g gain. Berge and Indrebo (1953; after Lewis et al., 1978) presented their data on a week-to-week basis and they found ratios of 4.0, 4.3, 5.0 and 5.3:1 for one to four weeks of lactation respectively.

**The correlation between milk nutrients output and growth of piglets.** The correlation coefficients between milk components intake and rate of gain are given in Table 9. The results indicate that in exp.1 the daily dry matter and energy intake of piglets via milk have somewhat higher correlation with daily gain of piglets than that of milk fat intake. In exp.2 the relationship between milk nutrient intake (dry matter, fat, energy) and daily gain of piglets was slightly less ( $r=0.40$  to  $0.41$ ). Noblet and Etienne (1989) found a high correlation between dry matter or energy output via milk and average daily gain of piglets ( $R^2=0.87$ ), however, they used a much greater range of sow feeding levels compared to our study (Table 3).

Lewis et al. (1978) regressed piglet gain on intake and they also reported low correlations between daily gain of piglets and percentage of milk solids ( $R^2=0.15$ ).

**Table 9. Correlation between daily gain of piglets<sup>a</sup> and daily intake of milk components<sup>b</sup> (between days 18 and 25 of lactation)**

	Milk nutrients			n
	Dry matter	Fat	Energy	
	Correlation coefficients (r)			
Experiment 1	0.69 <sup>***</sup>	0.57 <sup>**</sup>	0.66 <sup>**</sup>	27
Experiment 2	0.40 <sup>*</sup>	0.41 <sup>*</sup>	0.40 <sup>*</sup>	32

<sup>a</sup> Daily gain of piglets: g/d/piglet.

<sup>b</sup> Daily dry matter and fat intake: g/d/piglet; daily milk energy intake: kJ/d/piglet.

n= litters.

\*  $P < 0.05$ ; \*\*  $P < 0.01$ ; \*\*\*  $P < 0.001$ .

When they included yield, solids, and milk nitrogen percentage as independent variables in the multiple regression equation an increase in  $R^2$  value (0.45) was observed. They also stated that other factors that contribute to the variation in pig gain like environmental and genetic factors may be involved.

**Conclusion.** In conclusion it can be stated, that the live weight, backfat thickness and the milk production of sows were not affected by the different fat levels in the lactation diet. The high dietary fat content of the lactation diet can increase the dry matter, fat and energy content of milk and the daily gain of piglets in the second part of lactation. The utilization of milk and dry matter, fat, protein and energy content of milk for piglet growth was not influenced significantly by the dietary fat levels.

## References

- Adams, C.R. and C.R. Zimmerman. 1982. Many factors affect pigs' vitamin E needs. *Feedstuffs* 24: 30-31.
- Babinszky, L., D.J. Langhout, M.W.A. Verstegen, L.A. den Hartog, P. Joling and M. Nieuwland. 1991. Effect of  $\alpha$ -tocopherol and dietary fat source on some blood and immunological variables in lactating sows. *Anim. Prod.* 52: 367-375.
- Babinszky, L., D.J. Langhout, M.W.A. Verstegen, L.A. den Hartog, T. Zandstra, P.L.G. Bakker, and J.A.A.M. Verstegen. 1992. Dietary vitamin E and fat source and lactating performance of primiparous sows and their piglets. *Livest. Prod. Sci.* 30: 155-168.
- Boyd, R.D., B.D. Moser, E.R. Peo, Jr., A.J. Lewis, and R.K. Johnson. 1982. Effect of tallow and choline chloride addition to the diet of sows on milk composition, milk yield and preweaning pig performance. *J. Anim. Sci.* 54: 1-7.
- Centraal Veevoederbureau in Nederland (CVB). 1988. [*Dutch Feeding Tables.*] Centraal Veevoederbureau, The Netherlands.
- Chavez, E.R. and K.L. Patton. 1986. Response to injectable selenium and vitamin E on reproductive performance of sows receiving a standard commercial diet. *Can. J. Anim. Sci.* 66: 1065-1074.
- Coffey, M.T., R.W. Seerley and J.W. Mabry. 1982. The effect of source of supplemental dietary energy on sow milk yield, milk composition and litter performance. *J. Anim. Sci.* 55: 1388-1394.
- Drochner, W. 1989. Einflüsse von Fettzulagen an Sauen auf Aufzuchtleistungen und Fruchtbarkeit. [in German] *Übers. Tierernährg.* 17: 99-138.
- Hartog, den, L.A., M.W.A. Verstegen, H.A.T.M. Hermans, G.J. Noordewier and G.J.M. van Kempen. 1984. Some factors associated with determination of milk production in sows by weighing of piglets. *Zschrift Tierphys., Tierernährg. Futtermittelkunde* 51: 148-157.
- Klaver, J., G.J.M. van Kempen, P.G.B. de Lange, M.W.A. Verstegen and H. Boer. 1981. Milk composition and daily yield of different milk components as affected by sow condition and lactation/feeding regimen. *J. Anim. Sci.* 52: 1091-1097.
- Kroeske, D., A.J. Buiting, and G. de Jongh. 1968. Enkele criteria bij de bepaling van de slachtkwaliteit van varkens. [in Dutch] *Veeveelt- en Zuivelberichten* 11: 153-157.
- Lellis, W.A. and V.C. Speer. 1983. Nutrient balance of lactating sows fed supplemental tallow. *J. Anim. Sci.* 56: 1334-1339.
- Lewis, A.J., V.C. Speer and D.G. Haught. 1978. Relationship between yield and composition of sows' milk and weight gains of nursing pigs. *J. Anim. Sci.* 47: 634-638.
- Manz, U. and K. Philipp. 1981. A method for the routine determination of tocopherols in animal feed and human foodstuffs with the aid of high performance liquid chromatography. *Int. J. Vitam. Nutr. Res.* 51: 342-348.
- Moser, B.D. and A.J. Lewis. 1980. Adding fat to sow diets - An update. *Feedstuffs* 52: 36-38.
- Nelssen, J.L., A.J. Lewis, E.R. Peo, Jr. and B.D. Moser. 1985. Effect of source of dietary energy and energy restriction during lactation on sow and litter performance. *J. Anim. Sci.* 60: 171-178.
- Noblet, J. and M. Etienne. 1989. Estimation of sow milk nutrient output. *J. Anim. Sci.* 67: 3352-3359.
- Pettigrew, Jr., J.E. 1981. Supplemental dietary fat for periparturient sows: A review. *J. Anim. Sci.* 53: 107-117.
- Pharazyn, A., L.A. den Hartog and F.X. Aherne. 1990. Vitamin E and its role in the nutrition of the gilt and sow: a review. *Livest. Prod. Sci.* 24: 1-13.
- Schoenherr, W.D., T.S. Stahly and G.L. Cromwell. 1989. The effects of dietary fat or fiber addition on yield and composition of milk from sows housed in a warm or hot environment. *J. Anim. Sci.* 67: 482-495.
- Shurson, G.C. M.G. Hogberg, N. DeFever, S.V. Radecki and E.R. Miller. 1986. Effects of adding fat to the sow lactation diet on lactation and rebreeding performance. *J. Anim. Sci.* 62: 672-680.
- Statistical Analysis Systems Institute. 1990. *SAS, User's Guide: Statistics*. Statistical Analysis Systems Institute, Cary, NC.

---

Verstegen, M.W.A., W. van der Hel, H.A. Brandsma, A.M. Henken and A.M. Bransen. 1987. The Wageningen respiration unit for animal production research: a description of the equipment and its possibilities. In: M.W.A. Verstegen and A.M. Henken (Eds) Energy Metabolism in Farm Animals. pp. 21-48. Martinus Nijhoff Publishers, Dordrecht.

## Chapter 4

**Dietary vitamin E and fat source and lactating performance of primiparous sows and their piglets**

L. Babinszky<sup>1,3</sup>, D. J. Langhout<sup>1</sup>, M. W. A. Verstegen<sup>1</sup>, L. A. den Hartog<sup>2</sup>, T. Zandstra<sup>1</sup>,  
P.L.G. Bakker<sup>1</sup> and J.A.A.M. Verstegen<sup>1</sup>

<sup>1</sup> Department of Animal Nutrition, Agricultural University Wageningen, Haagsteeg 4, 6708 PM Wageningen, The Netherlands

<sup>2</sup> Research Institute for Pig Husbandry, P.O.Box 83, 5240 AB Rosmalen, The Netherlands

<sup>3</sup> Research Institute for Animal Nutrition, H-2053 Herceghalom, Hungary

## **Dietary vitamin E and fat source and lactating performance of primiparous sows and their piglets**

### **Abstract**

Two experiments were performed to study the effect of levels of vitamin E and sources of dietary fat on the reproductive performance and milk production of primiparous sows and on performance of suckling piglets. Experiment 1 was set up with two fat sources (sunflower oil and animal fat, 5% in the diet) and three levels of vitamin E (13, 48, 136 mg/kg feed). A total of 45 gilts (7-8 animals per treatment) received the same dietary treatment throughout pregnancy and 4 weeks of lactation. In experiment 2, two levels of vitamin E (14 and 126 mg/kg feed) were used in the diet during 4 weeks of lactation (15-16 sows per treatment) and the milk production was measured. It was concluded that the levels of vit. E and the types of fat used had no significant effect on the litter size and live weight of piglets during suckling. The milk yield was also not affected significantly by the dietary vitamin E levels. In the animal fat group, the higher vit. E intake increased the colostral vit. E content ( $P < 0.05$ ). At weaning the increase of vit. E in milk was somewhat clearer in sows fed animal fat than sunflower oil.

**Key Words:** Pigs , Vitamin E, Fat, Milk production.

### **Introduction**

Vitamin E [vit. E] appears to be essential for optimum function of many systems including nervous, circulatory, muscular and immune systems (Ullrey, 1981; Nockels 1986). This vitamin functions as an intra-cellular antioxidant (Putnam, 1982). Vit. E can affect the immune status of animals (Nockels, 1986).

It has been reported that the immune status of chickens, mice (Tengerdy et al., 1972, 1973) and weaning pigs (Peplowski et al., 1981) is improved by higher dietary vit. E intake. Vit. E may also influence reproductive performance of sows. This effect is more pronounced in older sows than in gilts (Chavez and Patton, 1986). Malm et al. (1976) found no significant effect of high vit. E supply on reproductive performance of 7-8 month-old sows fed with sunflower oil or animal fat. Vit. E also can increase milk production of sows, especially in second or higher parities (Adams and Zimmerman, 1982).

Several factors can influence the vit. E needs of swine, including the concentration of selenium and type of dietary fat (Adams and Zimmerman, 1982). Increasing the fat content of the diet, particularly

the polyunsaturated fatty acids (PUFA), increases the requirement for  $\alpha$ -tocopherol (Pharazyn et al., 1990).

Up to now only limited systematic examinations have been carried out with different combinations of dietary fat and vit. E in sow nutrition. Therefore in a series of experiments in the Department of Animal Nutrition, the effect was studied of type of dietary fat and the level of vit. E in the diet of sows on the immune status of the sows (Babinszky et al., 1991a) and on the immune response of their piglets (Babinszky et al., 1991b). In the present study, within the frame of this research program, two experiments were conducted to determine the effect of different levels of vit. E and fat source in the diet on reproductive performance and milk production of primiparous sows and on performance of suckling piglets.

## Materials and Methods

### *Experiment 1*

**Animals.** A total of 45 PIC (Pig Improvement Company, England) hybrid first litter, 7-month-old gilts was used in two batches. Animals were bred with Dutch Yorkshire boars at the experimental unit of the University.

**Experimental design and diets.** The experiment was set up with two different fat sources and three levels of vit. E in sow diets in a 2 x 3 factorial arrangement (Table 1).

The fat source was either an unsaturated vegetable fat [V] (sunflower oil: commercial cooking oil) or a saturated animal fat [A] (slaughtering waste, packing house by-product; Nederlandse Thermo-Chemische Fabrieken, Netherlands). These fats were included in the diets at a level of 5 % (Table 2). The basal diets contained 13 mg of vit. E (as  $\alpha$ -tocopherol) per kg feed (low level= L). These diets were supplemented with DL- $\alpha$ -tocopheryl acetate to 48 (medium= M) and 136 (high= H) mg of  $\alpha$ -tocopherol per kg diet (average analysed values, Table 1). The reason for using high vit. E level was also to study the effect of vit. E on some blood and immunological traits in lactating sows and their piglets (Babinszky et al., 1991a, 1991b). The selenium content of the diets was 0.1 mg per kg feed.

**Feeding and housing.** The experiment started 3 weeks after mating and lasted until the piglets were 4 weeks of age (4 weeks of suckling). In each treatment the sows received the same diet throughout pregnancy and lactation. The major components of diets are given in Table 2. During pregnancy, gilts were fed 30 MJ ME/d (2.4 kg/d per gilt) from day 21 after insemination onwards in individual feeding crates. On day 110 of gestation each gilt was moved to a farrowing crate. During lactation sows received feed at a level of 1% of body weight and additionally 0.5 kg per piglet. During suckling no creep feed was given. In each treatment group reproduction parameters were measured with 7 or

8 gilts. Six gilts were used for milk sampling. Water was administered ad libitum for sows and piglets during the experiment.

**Table 1. Experimental arrangements (Exp.1 and Exp.2)**

Experiment	Treatment	Codes <sup>a</sup>	Vitamin E <sup>b</sup> in sow's diet (mg/kg feed)	Fat and energy source in sow diet
1	1	LV	12	sunflower oil
	2	MV	45	sunflower oil
	3	HV	132	sunflower oil
	4	LA	14	animal fat
	5	MA	50	animal fat
	6	HA	140	animal fat
2	1	LSt	13	starch
	2	HSt	117	starch
	3	LA	16	animal fat
	4	HA	135	animal fat

<sup>a</sup> Vitamin E: L (low), M (medium), H (high).  
Fat source: V (vegetable fat), A (animal fat).  
Energy source: St (starch), A (animal fat).

<sup>b</sup> Analysed values (as  $\alpha$ -tocopherol).

**Colostrum-, milk- and feed sampling.** Colostrum was collected by hand from all functional nipples during farrowing. Milk samples were obtained at weaning using oxytocin injection according to the method described by Babinszky et al. (1991a). Experimental diets were sampled for analysis of nutrient content and for  $\alpha$ -tocopherol twice each week.

**Weight and backfat thickness.** Sows and piglets were weighed individually after farrowing and at weaning. The backfat thickness of sows was measured ultrasonically after farrowing and also at weaning. The measuring was done on four different points on the back, 5 cm from the dorsal mid-line according to Kroeske et al. (1968). An average of these points was used per animal as mean backfat thickness.

**Milk and feed analysis.** Alpha-tocopherol content in the feed and milk were analysed by a high performance liquid chromatography (HPLC) method (Manz and Philipp, 1981; Vuilleumier et al., 1983) by Hoffmann - La Roche Ltd. (Basle, Switzerland). In colostrum and milk samples, dry matter was determined by freeze-drying milk (ISO 6496, 1983), subsequently ash was determined in the freeze dried milk (ISO 5984, 1978).

**Table 2. Major components of diets for pregnant and lactating sows (Exp.1)**

Composition (g/kg)	Diet 1 <sup>a</sup>	Diet 2 <sup>b</sup>
Wheat middlings	158	148
Corn gluten feed	150	150
Soya-bean meal	180	182
Tapioca meal	297	320
Sunflower oil	50	-
Animal fat	-	50
Vitamin-mineral premix <sup>c</sup>	5	5
Other components <sup>d</sup>	160	145
Nutrient content		
as analysed (g/kg DM)		
Crude protein	178	175
Crude fat	71	75
as calculated		
Metabolizable energy, <sup>e</sup> MJ/kg DM	14.30	14.29
Digestible lysine, <sup>f</sup> g/kg DM	7.44	7.33

<sup>a</sup> For treatments 1, 2, 3.

<sup>b</sup> For treatments 4, 5, 6.

<sup>c</sup> 1 kg basal premix for sows contained: DL- $\alpha$ -tocopheryl acetate 2400 mg, selenium 20 mg.

<sup>c,d</sup> See also Babinszky et al.(1991a).

<sup>e</sup> Calculated from net energy according to Centraal Veevoederbureau (CVB, 1988) and assuming net energy is 70% of metabolizable energy.

<sup>f</sup> Faecal digestibility (CVB, 1988).

Nitrogen percentage was determined by Kjeldahl method and 6.38 was used as a factor to determine protein content (ISO 5983, 1979). Fat content was determined after acid hydrolysis by ISO-DIS 6492 (1985). Fat content was determined according to the method of Röse-Gottlieb (Ritter et al., 1967) by Hoffmann - La Roche Ltd. to allow expression of the  $\alpha$ -tocopherol concentration in  $\mu\text{g/g}$  of fat. Lactose content was calculated by subtracting fat, protein and ash from dry matter content. The nutrient contents of diets (dry matter, crude protein, crude fat) were analysed as described by Babinszky et al.(1991a).

### Experiment 2

**Animals.** A total of 32 first litter PIC hybrid gilts was used in four batches of 8 animals each. (One animal in batch 1 had to be removed from the experiment).

**Experimental design and diets.** In this experiment the different dietary energy sources were tapioca starch [St] or animal fat [A] (Table 1). The animal fat was the same product as that described in experiment 1. Both basal diets contained low levels of vit. E [L] (13 and 16 mg of  $\alpha$ -tocopherol/kg

feed) and these diets were supplemented with DL- $\alpha$ -tocopheryl acetate to a high level of vit. E [H] (117 and 136 mg  $\alpha$ -tocopherol/kg feed, Table 1). The main components of the basal diets are given in Table 3. The animals in batch 1 were fed with diets LSt and LA and in batch 2 with diets HSt and HA. In batches 3 and 4 the animals received the same diets as in batches 1 and 2. Within each batch, four animals were assigned per diet.

**Table 3. Major components of diets for lactating sows (Exp.2)**

Composition (g/kg)	Diet 1 <sup>a</sup>	Diet 2 <sup>b</sup>
Hominy feed	77	150
Corn	103	30
Sunflower seed	85	36
Soya-bean meal, solv. extr.	80	125
Soya-bean heat treated	68	29
Peas	65	58
Molasses beet	40	60
Beet pulp	-	50
Tapioca meal	386	196
Animal fat	-	37
Vitamin-mineral premix <sup>c</sup>	7.5	7.5
Other components <sup>d</sup>	88.5	221.5
Nutrient content		
as analysed, g/kg DM		
Crude protein	188	193
Crude fat	43	75
Starch	396	286
as calculated		
Metabolizable energy <sup>e</sup> , MJ/kg DM	14.27	14.27
Digestible lysine <sup>f</sup> , g/kg DM	7.44	7.44

<sup>a</sup> For treatments 1, 2.

<sup>b</sup> For treatments 3, 4.

<sup>c</sup> 1 kg basal premix contained: calcium 157 g, sodium 157 g, potassium 21 mg, iron 10 000 mg, copper 3333 mg, zinc 10 667 mg, manganese 4000 mg, cobalt 33 mg, iodine 67 mg, selenium 27 mg, all-trans-retinyl acetate 459 mg, cholecalciferol 7 mg, thiamin 67 mg, riboflavin 533 mg, pyridoxine 67 mg, d-panthotenic acid 1733 mg, nicotinic acid 2000 mg, biotin 7 mg, cyanocobalamin 2 mg, vitamin K<sub>3</sub> 67 mg, DL-alpha-tocopheryl acetate 2000 mg, folic acid 13 mg, choline chloride 60 000 mg.

<sup>d</sup> Meat meal tankage, corn gluten feed, coconut expeller, palm kernel expeller, limestone, bicalciumphosphate, DL-lysine, DL-methionine.

<sup>e</sup> Calculated from net energy according to Centraal Veevoederbureau (CVB, 1988) and assuming net energy is 70% of metabolizable energy.

<sup>f</sup> Faecal digestibility (CVB, 1988).

**Feeding.** The experiment started after farrowing and lasted until weaning at 4 weeks of lactation. During pregnancy, gilts were fed at the level described in experiment 1, with a diet containing 15 mg vit. E/kg feed. During lactation, sows received the diet at a level of 1% of body weight plus 0.4 kg per piglet. Creep feed was not provided. Litter size after farrowing was standardized to 10 piglets in batch 1 and to 9 piglets in batches 2, 3 and 4.

**Measuring of milk production.** On days 6, 11, 16, 21 and 26 of lactation milk production was determined by weighing the litter before and after suckling. The duration of suckling and the weight of litter before and after suckling were measured. Correction for metabolic rate, evaporation, urination and defaecation of piglets was made. The procedure in each suckling period was:

- |  |                               |
|--|-------------------------------|
| 1) resting period after previous suckling: | 53 min (not with sow);        |
| 2) weighing of litter (before suckling):   | approx. 1 min (not with sow); |
| 3) suckling period (litter with the sow):  | approx. 5 min (with sow);     |
| 4) weighing of litter (after suckling):    | approx. 1 min (not with sow). |

Weight of the litter before and after suckling was determined with an electronic balance (Mettler/Sauter EC 240 HD) connected to an Epson HX 20 portable computer, which calculated the mean of 15 separate measurements. At the same time, the litter was measured five times within a few seconds and the average of five values was then used as a measure of two different weights for calculation of milk production. Milk production was determined in this way at five-six subsequent sucklings on each measuring day.

The metabolic weight loss of piglets was measured by simulating the activity of the litter during suckling by placing piglets in a box and moving this box continuously during 4.5 min without allowing them to suckle. The litter was weighed before and after this activity. The weight loss of the piglets was calculated on the basis of piglet weight losses during the activity. The metabolic weight loss of the piglets was measured once on the measuring day. The calculation resulted in the following regression:

$$Y = 0.0058X - 0.0022 \quad (R^2 = 0.26, n=104, RMSE = 0.0074)$$

where: Y = total weight loss in g per second due to metabolic rate and evaporation, X = metabolic weight of piglet in the litter ( $\text{kg}^{0.75}$ ).

The effect of urination and defaecation on the change of the litter weight during suckling was estimated by regression using GLM procedure from the SAS-package (SAS, 1985). These regression equations for weight changes were expanded with corrections for day of suckling as class variables. Urination and defaecation occurred in less than 4 and 2 % of all observations, respectively. The corrected hourly milk production per sow was multiplied by 24 to give daily milk production.

**Nutrient content of diets.** Dry matter, crude protein, crude fat and  $\alpha$ -tocopherol contents were analysed as described in experiment 1. Starch was determined after gelatinization (during 3 h at 130°C) and hydrolysis with amyloglucosidase and determination of glucose according to the Boehringer Mannheim method for starch (1989).

### Statistical analysis

Data per measuring day were analysed by the following models:

#### Experiment 1.

$$Y_{ijkl} = \mu + A_i + B_j + (AB)_{ij} + C_k + e_{ijkl} \quad (1)$$

in which:  $Y_{ijkl}$  = dependent variable;  $\mu$  = mean;  $A_i$  = type of fat in sow's diet ( $i = 1, 2$ );  $B_j$  = vit. E level in sow's diet ( $j = 1, 2, 3$ );  $(AB)_{ij}$  = interaction between fat and vit. E;  $C_k$  = batch ( $k = 1, 2$ ) and  $e_{ijkl}$  = residual error.

This model for analysis of data weight of piglets was extended by litter size at the end of lactation. It has been previously established that birth litter size and weaning litter size had similar effects. Interactions, batch and litter size were omitted if not significant.

#### Experiment 2.

Data in experiment 2 were analysed as follows: Since only one vit. E level was used in each batch, the effect of energy source was tested directly. This means that part of the variation between batches was related to vit. E level in the sow's diet. Therefore the batches are nested within vit. E level, permitting examination of the vit. E effect against the batch variation within vit. E levels. No significant interactions between energy source and vit. E level were found. The following model was used:

$$Y_{ijkl} = \mu + A_i + B_j + C(B)_{k(j)} + e_{ijkl} \quad (2)$$

where:  $Y_{ijkl}$  = dependent variable;  $\mu$  = mean;  $A_i$  = type of energy source in sow's diet ( $i = 1, 2$ );  $B_j$  = vit. E level in sow's diet ( $j = 1, 2$ );  $C(B)_{k(j)}$  = batch variation within vit. E levels ( $k(j) = 1, 2, 3, 4$ ); and  $e_{ijkl}$  = residual error.

Analysis of variance was done by GLM procedure (SAS, 1985) for all values in both experiments. When significant effects were obtained, differences between means were compared by the Tukey-test (SAS, 1985).

## Results and Discussion

### *Live weight and backfat thickness of sows (Exp.1)*

No significant differences between treatments were found with regard to live weight of sows post partum and at weaning (range of treatment groups after farrowing was from 168 to 171 kg, at weaning from 141 to 152 kg). The backfat thickness of sows was also not affected by the combinations of vit. E and fat (range of treatment groups after farrowing was from 15.3 to 18.3 mm, at weaning from 11.3 to 14.5 mm). The daily feed intake of sows during lactation was also similar in all treatment groups: mean 4.6 kg/sow, range 4.4 to 4.7 kg/sow. On the basis of these results we concluded that the combinations of vit. E and dietary fat source had no significant effect on the live weight or on the backfat thickness of sows.

### *Milk production of sows (Exp.2)*

Results for milk production in the present study are shown for the different levels of vit. E in the sow's diet (Table 4). Data are given as least square means (LSM) per vit. E group. For the calculation

**Table 4. Effect of dietary vitamin E on the daily milk production of primiparous sows (Exp.2) Least square means, (kg milk per piglet)**

Stage of lactation (day)	Vitamin E in lactating diet <sup>a</sup>		RMSE <sup>b</sup>
	L	H	
6	0.57	0.66	0.11
11	0.80	0.89	0.15
16	0.88	0.92	0.16
21	1.02	1.04	0.14
26	1.09	1.02	0.17

<sup>a</sup> L (low level), 14 mg/kg diet; H (high level), 126 mg/kg diet.

<sup>b</sup> Root mean square error.

of LSM in the low and high vit. E groups, 8 and 15 sows were used at day 6, 14 and 15 at day 11 and 15 and 16 sows at days 16, 21, 26 of lactation. From this table it can be seen that the milk yield during lactation was not affected significantly by the vit. E level in the sow's diet. However, it should be noted that the milk production on the first three measuring days in the high vit. E group was somewhat higher than in the low vit. E group. We made a similar observation in a subsequent study using the same vit. E levels (Babinszky et al., 1991, unpublished data). Nielsen et al. (1979) found that a high dietary level of selenium or vit. E did not significantly alter milk production of sows. However, they also observed that milk yield of sows was higher following additions of both selenium and

vit. E. Adams and Zimmerman (1982) reported that multiparous sows fed supplemental vit. E had increased milk production compared with unsupplemented sows. In the current study, first lactation sows were used. This may be the reason why no clear vit. E effect was found.

#### Composition of colostrum and milk (Exp.1)

The major components of colostrum and milk are given in Table 5. No significant differences were found in colostrum composition for the dietary vit. E and in fat (average ash and lactose content in colostrum were 7 and 33 g/kg, respectively). At the end of lactation, dry matter content in milk was highest in the medium vit. E group ( $P < 0.05$ ). In the vegetable fat group the dry matter content was also higher ( $P < 0.05$ ) than in the animal fat group. Protein content was not affected by vit. E level or by fat source in the sow's diet. Fat content in the medium vit. E group was the highest ( $P < 0.05$ ).

Table 5. Mean dry matter, protein and fat content of colostrum and milk (g/kg), (Exp.1)

Item	Dietary vit.E <sup>a</sup>			Dietary fat <sup>a</sup>		RMSE <sup>b</sup>
	L	M	H	V	A	
Colostrum <sup>c</sup>						
n (sows)	11	11	11	17	16	
Dry matter	283	265	285	269	287	27
Protein	168	163	178	160	179	21
Fat	74	61	68	67	68	17
Milk <sup>d</sup>						
n (sows)	12	12	12	18	18	
Dry matter	200 <sup>f</sup>	212 <sup>e</sup>	197 <sup>f</sup>	211 <sup>x</sup>	195 <sup>y</sup>	12
Protein	54	57	54	56	53	5
Fat	86 <sup>ef</sup>	96 <sup>e</sup>	83 <sup>f</sup>	95 <sup>x</sup>	81 <sup>y</sup>	11

<sup>a</sup> Codes are defined in Table 1.

<sup>b</sup> Root mean square error.

<sup>c</sup> During farrowing.

<sup>d</sup> At weaning.

<sup>e,f</sup> Different superscripts in the same row indicate significant differences among vit. E groups at  $P < 0.05$ .

<sup>x,y</sup> Different superscripts in the same row indicate significant differences among fat groups at  $P < 0.05$ .

These results may indicate that medium vit. E in sow's diet may be more beneficial to the fat content in the milk than a high level. Whether milk fat content is affected by the dietary vit. E must be elucidated in further experiments. The sunflower oil group showed higher fat content than the animal fat group ( $P < 0.05$ ) (average ash and lactose content in milk were 8,5 and 51 g/kg, respectively).

Loudenslager et al. (1986) did not find the effects of vit. E and selenium on fat content in colostrum and milk in second parity sows. Pettigrew (1981) reported data which suggested higher fat content in milk from sows fed corn oil compared to animal fat. Seerley et al. (1981) noted that the total lipid content in colostrum and milk was not affected by dietary corn oil or animal fat.

#### *Alpha-tocopherol content in colostrum and milk (Exp.1)*

Results for  $\alpha$ -tocopherol (vit. E) content in colostrum and milk are summarized in Table 6. Values show that vit. E in sunflower oil groups had no significant effect on vit. E level in colostrum fat content. However, the vit. E content in the high vit. E group with animal fat differed ( $P < 0.05$ ) from all other groups. In the animal fat group there was an interaction between fat and dietary vit. E because in the low vit. E group the vit. E level was low. However, it should be noted that serum vit. E in this group was also the lowest ( $P < 0.05$ ) (Babinszky et al., 1991a). This may indicate that the animals in the LA group reserved more vit. E in their body. At weaning, in both sunflower oil and animal fat groups, the highest value was found in high vit. E groups. However, the difference between the low and high vit. E groups was significant only when animal fat was included in the diet.

**Table 6. Mean alpha-tocopherol concentration in colostrum and milk ( $\mu\text{g/g}$  fat), (Exp.1)**

Item	Fat:	Sunflower oil			Animal fat			RMSE <sup>a</sup>
	Vit.E <sup>b</sup> :	L	M	H	L	M	H	
Colostrum		334 <sup>y</sup>	392 <sup>y</sup>	449 <sup>y</sup>	182 <sup>z</sup>	429 <sup>y</sup>	593 <sup>x</sup>	71
Milk		46 <sup>xy</sup>	48 <sup>xy</sup>	66 <sup>x</sup>	14 <sup>z</sup>	30 <sup>yz</sup>	64 <sup>x</sup>	13

<sup>a</sup> Root mean square error.

<sup>b</sup> Codes are defined in Table 1.

<sup>x,y,z</sup> Different superscripts in the same row indicate significant differences among treatments at  $P < 0.05$ .

Data on the vit. E concentration in the present study show that a high level of dietary vit. E in the gestation diet had a greater effect on concentration of colostrum vit. E with animal fat than with sunflower oil. At weaning there was no difference between the HV and HA groups. Cline et al. (1974), Young et al. (1977) and Loudenslager et al. (1986) also found that the vit. E content of sow colostrum and milk was increased with extra vit. E in the diet. We also found an increase in concentrations of vit. E in colostrum and milk when sows were fed a high vit. E level. This increase was clearer in the animal fat group than in the sunflower oil group. Malm et al. (1976) also found that animal fat from lard tended to promote a higher concentration of vit. E in milk fat than did corn oil,

but the difference was not significant. Chavez and Patton (1986), however, reported that the vit. E content in colostrum was not affected by the injection of vit. E and selenium during pregnancy.

#### *Mean litter size and live weight of piglets during suckling (Exp.1)*

As can be seen from Table 7, the number of piglets at birth and at weaning (4 weeks of age) was not affected by any of the six treatments applied. Nielsen et al. (1979) reported that a higher level of selenium and vit. E in the sow's diet had no significant effect on litter size (vit. E in basal and exp. diet 15 and 45 IU/kg).

**Table 7. Mean litter size and live weight of piglets during suckling (Exp.1)**

Item	Fat:	Sunflower oil			Animal fat			RMSE <sup>a</sup>
	Vit.E <sup>b</sup> :	L	M	H	L	M	H	
n (litters)		7	8	8	8	7	7	
Litter size								
Total piglets born		10.7	12.0	10.1	11.0	11.3	10.3	2.9
Piglets born alive		10.4	11.6	9.8	10.5	11.0	9.9	2.8
Number of piglets at weaning <sup>c</sup>		9.7	10.5	9.2	8.8	9.7	8.6	2.6
Weight of piglets								
at birth		1.32	1.29	1.35	1.24	1.25	1.49	0.18
at weaning <sup>c</sup>		6.57	6.46	7.32	6.94	6.50	7.23	0.68

<sup>a</sup> Root mean square error.

<sup>b</sup> Codes are defined in Table 1.

<sup>c</sup> 4 weeks of age.

Malm et al. (1976) showed that litter size at birth was not significantly influenced by the level of vit. E with corn oil or animal fat. However, in other studies it was observed that injection of vit. E and selenium (Chavez and Patton, 1986) or supplementation of the sow's diet with vit. E (Adams and Zimmerman, 1982) may increase the litter size. This positive effect was more pronounced in multiparous sows than in gilts. In the present investigation we used gilts, which may explain why no treatment effect was found.

Live weights of piglets at birth and at weaning are given also in Table 7. There were no significant differences between treatment groups at birth and at weaning. Malm et al. (1976) found no treatment effect on pig birth weight and weaning weight when sows received low or high levels of vit. E with corn oil or animal fat. Nielsen et al. (1979) similarly reported no significant effect of higher level of selenium and vit. E in the sow's diet on weight of piglets at birth and at 8 weeks of age. But low

dietary levels of selenium and vit. E were followed by increased mortality in piglets. On the other hand, Chavez and Patton (1986) found greater total litter weight at birth and at weaning after vit. E and selenium injections, although the response to the treatment was greater in older sows than in young ones.

## **Conclusion**

The present study indicates that vit. E level and type of dietary fat (sunflower oil or animal fat) in the diet of primiparous sows had no significant effect on their reproductive performance (litter size, piglets' birth weight, weaning weight). The milk production of sows was not affected by the applied level of vit. E. The results suggest that an increase of vit. E in the pregnancy diet combined with animal fat may increase the colostral vit. E. At weaning the increase of vit. E content in milk was more pronounced in the animal fat group than in the sunflower oil group.

## References

- Adams, C.R. and C.R. Zimmerman. 1982. Many factors affect pigs' vitamin E needs. *Feedstuffs* 24: 30-31.
- Babinszky, L., D.J. Langhout, M.W.A. Verstegen, L.A. den Hartog, P. Joling and M. Nieuwland. 1991a. Effect of alpha-tocopherol and dietary fat source on some blood and immunological variables in lactating sows. *Anim. Prod.* 52: 367-375.
- Babinszky, L., D.J. Langhout, M.W.A. Verstegen, L.A. den Hartog, P. Joling and M. Nieuwland. 1991b. Effect of vitamin E and fat source in sow diet on immune response of suckling and weaned piglets. *J. Anim. Sci.* 69: 1833-1842.
- Boehringer Mannheim, 1989. Instructions for the Analysis. Methods of Biochemical Analysis and Food Analysis. Boehringer Mannheim GmbH, Biochemica, Mannheim, Germany, 142 pp.
- Centraal Veevoederbureau in Nederland (CVB), 1988. [Dutch Feeding Tables]. Centraal Veevoederbureau, Lelystad, The Netherlands., (in Dutch).
- Chavez, E.R. and K.L. Patton. 1986. Response to injectable selenium and vitamin E on reproductive performance of sows receiving a standard commercial diet. *Can. J. Anim. Sci.* 66: 1065-1074.
- Cline, J.H., D.C. Mahan, and A.L. Moxon. 1974. Progeny effects of supplemental vitamin E in sow diets. *J. Anim. Sci.* 39: 974. (Abstract).
- ISO (International Organization for Standardization), Animal Feeding stuffs: Determination of moisture content. 1983 (ISO 6496); Determination of nitrogen content and calculation of crude protein content. 1979 (ISO 5983); Determination of crude ash. 1978 (ISO 5984); Determination of fat by extraction. 1985 (ISO-DIS 6492).
- Kroeske, D., G.A.J. Buiting and G. De Jongh. 1968. Enkele criteria bij de bepaling van de slachtkwaliteit van varkens. *Veeeteelt Zuivelber.* 11: 153-157 (in Dutch).
- Loudenslager, M.J., P.K. Ku, P.A. Whetter, D.E. Ullrey, C.K. Whitehair, H.D. Stowe and E.R. Miller. 1986. Importance of diet of dam and colostrum to the biological antioxidant status and parenteral iron tolerance of the pig. *J. Anim. Sci.* 63: 1905-1914.
- Malm, A., W.G. Pond, E.F. Walker, M. Homan, A. Aydin and D. Kirtland. 1976. Effect of polyunsaturated fatty acids and vitamin E level of the sow gestation diet on reproductive performance and on level of alpha tocopherol in colostrum, milk and dam and progeny blood serum. *J. Anim. Sci.* 42: 393-399.
- Manz, U. and K. Philipp. 1981. A method for the routine determination of tocopherols in animal feed and human foodstuffs with the aid of high performance liquid chromatography. *Int. J. Vitam. Nutr. Res.* 51: 342-348.
- Nielsen, H.E., V. Danielsen, M.G. Simesen, G. Gissel-Nielsen, W. Hjarde, T. Leth and A. Basse. 1979. Selenium and vitamin E deficiency in pigs. I. Influence on growth and reproduction. *Acta Vet. Scand.* 20: 276-288.
- Nockels, C.F., 1986. Nutrient modulation of the immune system. In: W. Haresign and D.J.A. Cole (Eds), Recent Advances in Animal Nutrition. Butterworths, London, pp. 177-192.
- Peplowski, M.A., D.C. Mahan, F.A. Murray, A.L. Moxon, A.H. Cantor, and K.E. Ekstrom. 1981. Effect of dietary and injectable vitamin E and selenium in weanling swine antigenically challenged with sheep red blood cells. *J. Anim. Sci.* 51: 344-351.
- Pettigrew, J.E.Jr., 1981. Supplemental dietary fat for peripartur sows: a review. *J. Anim. Sci.* 53: 107-117.
- Pharazyn, A., L.A. den Hartog and F.X. Aherne. 1990. Vitamin E and its role in the nutrition of the gilt and sow: a review. *Livest. Prod. Sci.* 24: 1-13.
- Putnam, M.E., 1982. Vitamin E for pigs. *Pig Vet. Soc. Proc.* 9: 178-183.
- Ritter, W., H. Baumgartner, H. Hänni, P. Schilt, J. Stein and R. Walser. 1967. Fett-Bestimmung gravimetrisch, nach Röse-Gottlieb. In: Schweizerisches Lebensmittelbuch. Methoden für die Untersuchung und Beurteilung von Lebensmitteln und Gebrauchsgegenständen. 2. Band-Spezieller Teil, Eidg. Drucksachen- und Materialzentrale, Bern, pp. 21-22.

- SAS (Statistical Analysis Systems Institute), 1985. SAS, User's Guide: Statistics. SAS Inst., Cary, NC, 956 pp.
- Seerley, R.W., R.A. Snyder and H.C. McCampbell. 1981. The influence of sow dietary lipids and choline on piglet survival, milk and carcass composition. *J. Anim. Sci.* 52: 542-550.
- Tengerdy, R.P., R.H. Heinzerling and C.F. Nockels. 1972. Effect of vitamin E on the immune response of hypoxic and normal chickens. *Infect. Immun.* 5: 987-989.
- Tengerdy, R.P., R.H. Heinzerling, G.L. Brown and M.M. Mathias. 1973. Enhancement of the humoral immune response by vitamin E. *Int. Arch. Allergy.* 44: 221-232.
- Ullrey, D.E., 1981. Vitamin E for swine. *J. Anim. Sci.* 53: 1039-1056.
- Vuilleumier, J.P., H.E. Keller, D. Gysel and F. Hunziker. 1983. Clinical chemical methods for the routine assessment of the vitamin status in human populations. Part I. The fat-soluble vitamins A and E, and  $\beta$ -carotene. *Int. J. Vitam. Nutr. Res.* 53: 265-272.
- Young, L.G., R.B. Miller, D.E. Edmeades, A. Lun, G.C. Smith and G.J. King. 1977. Selenium and vitamin E supplementation of high moisture corn diets for swine reproduction. *J. Anim. Sci.* 45: 1051-1060.

## Chapter 5

**Effect of  $\alpha$ -tocopherol and dietary fat source on some blood and immunological variables in lactating sows**

L. Babinszky<sup>1,4</sup>, D. J. Langhout<sup>1</sup>, M. W. A. Verstegen<sup>1</sup>, L. A. den Hartog<sup>3</sup>, P. Joling<sup>2</sup>,  
and M. Nieuwland<sup>2</sup>

<sup>1</sup> Department of Animal Nutrition, Agricultural University Wageningen, Haagsteeg 4, 6708 PM Wageningen, The Netherlands

<sup>2</sup> Department of Animal Husbandry, Agricultural University Wageningen, Marijkeweg 40, 6709 PG Wageningen, The Netherlands

<sup>3</sup> Research Institute for Pig Husbandry, P.O.Box 83, 5240 AB Rosmalen, The Netherlands

<sup>4</sup> Research Institute for Animal Nutrition, H-2053 Herceghalom, Hungary

## Effect of $\alpha$ -tocopherol and dietary fat source on some blood and immunological variables in lactating sows

### Abstract

Thirty-six 7-month-old gilts were used to study the effects of different levels of  $\alpha$ -tocopherol (13, 48, 136 mg/kg food) and different source of fat (50 g/kg sunflower oil or animal fat) in gestation and lactation diets on  $\alpha$ -tocopherol concentration in serum, colostrum and milk and on cell-mediated and humoral immune response of lactating sows.

Blood samples were taken from six sows per treatment after farrowing and at weaning (28 days of lactation) and were analysed for  $\alpha$ -tocopherol concentration, total number of leucocytes and T- and B-lymphocyte counts. In blood lymphocyte stimulation with concanavaline, lysozyme activity and immunoglobulin concentration were also measured. In milk samples  $\alpha$ -tocopherol and immunoglobulin concentration were determined at farrowing and at weaning. It was concluded that a high  $\alpha$ -tocopherol level in the sow's diet including either sunflower oil or animal fat increased as expected the serum  $\alpha$ -tocopherol concentration ( $P < 0.05$ ) just after farrowing and at weaning. In colostrum the combination of high  $\alpha$ -tocopherol with animal fat gave the highest ( $P < 0.05$ )  $\alpha$ -tocopherol concentration. At weaning  $\alpha$ -tocopherol in milk fat was highest in both fat groups with extra high  $\alpha$ -tocopherol in the diet. The cell-mediated immunity of sows as tested were not systematically affected by  $\alpha$ -tocopherol supplementation or fat addition to diet. However, the humoral immune system may be affected by the combinations of  $\alpha$ -tocopherol and fat given.

**Key Words:** dietary fat, immune response, lactation, sows,  $\alpha$ -tocopherol.

### Introduction

From various investigations it has been reported that  $\alpha$ -tocopherol plays an important role in improving the reproductive performance of sows (Adams and Zimmerman, 1982; Chavez and Patton, 1986). It appears to function as an intra-cellular anti-oxidant (Putnam, 1982). It can inhibit the aggregation of blood platelets and stimulate the immune response in animals (Tengerdy et al., 1972; Ullrey, 1981).

Pre-treatment of animals with  $\alpha$ -tocopherol either in the diet or by injection has been shown to enhance the immune response so that resistance to an infectious disease is improved (Nockels, 1983). The supplementation of diets with  $\alpha$ -tocopherol has also been shown to result in increased phagocytosis, antibody production and cell-mediated immunity (Nockels, 1986).

Many factors can influence the  $\alpha$ -tocopherol needs of pigs, including the concentration of selenium in diets and also stress factors (Adams and Zimmerman, 1982). It has also been stated in many reports that increasing the fat content of the diet, particularly the polyunsaturated fatty acid (PUFA) content, increases the requirement for  $\alpha$ -tocopherol (Pharazyn et al., 1990). Therefore, for growing pigs the Agricultural Research Council (1981) suggested that dietary  $\alpha$ -tocopherol level should be increased by 0.25 mg D- $\alpha$ -tocopherol per g PUFA in the diet. Malm et al. (1976) reported that serum  $\alpha$ -tocopherol concentration of sows during gestation and just before farrowing was reduced with low dietary  $\alpha$ -tocopherol and was increased with lard plus  $\alpha$ -tocopherol compared with maize oil plus  $\alpha$ -tocopherol. Hayek et al. (1989) found that a single pre-partum injection of selenium and/or  $\alpha$ -tocopherol on day 100 of gestation increased IgG concentrations in serum from pigs at day 14 of lactation. Results of their experiments indicated that pre-partum injection of sows with  $\alpha$ -tocopherol and selenium influences immunoglobulin transfer to their piglets.

The purpose of the work reported here was to study the effects of different levels of  $\alpha$ -tocopherol and different types of dietary fat (unsaturated and saturated) in gestation and lactation diets on  $\alpha$ -tocopherol and immunoglobulin concentration in colostrum, milk and blood serum and on cell-mediated and humoral immune response of lactating sows.

## Materials and Methods

### *Animals*

A total of 36 PIC (Pig Improvement Company, England) hybrid first litter, 7-month-old gilts were used in two batches.

### *Experimental design and diets*

In each batch two different fat sources and three levels of  $\alpha$ -tocopherol were used in the diet in a 2 x 3 factorial design (Table 1).

The fat source was either an unsaturated vegetable fat [V] (sunflower oil: commercial cooking oil) or a saturated animal fat [A] (slaughtering waste, packing house by-product; NTF, The Netherlands). These fat sources were included in the diet at a level of 50 g/kg (Table 2).

The basal diets contained 13 mg vitamin E as  $\alpha$ -tocopherol per kg food (low level=L) and these diets were supplemented by DL- $\alpha$ -tocopheryl acetate to 48 (medium level=M) and 136 (high level=H) mg  $\alpha$ -tocopherol per kg food (average analysed values). The selenium content of the diets was 0.1 mg / kg food.

Table 1. Experimental design

Treatment	Code <sup>a</sup>	Vitamin E <sup>b</sup> mg/kg food	Fat source
1	LV	12	sunflower oil
2	MV	45	sunflower oil
3	HV	132	sunflower oil
4	LA	14	animal fat
5	MA	50	animal fat
6	HA	140	animal fat

<sup>a</sup>Vitamin E level: L (low); M (medium); H (high). Dietary fat: V (vegetable fat); A (animal fat).

<sup>b</sup>Analysed values (as  $\alpha$ -tocopherol).

#### *Feeding and housing*

For the pregnant and lactating sows the same diets were used. During pregnancy the sows were given 30 MJ metabolizable energy per day (2.4 kg food per day per sow). During lactation sows received daily food at a level of 0.01 of body weight and additionally 0.5 kg per piglet. The experiment started at mating and lasted until weaning at 28 days of lactation. Animals received the experimental diet from day 21 after insemination onwards. Six gilts were used per treatment. During pregnancy animals were housed in groups with wood shavings as bedding material. They were given food twice daily in individual feeding crates. On day 110 of gestation each gilt was moved to a farrowing crate. Crates were provided with shavings as bedding material. Water was available ad libitum during pregnancy and lactation.

#### *Blood, milk and food sampling*

Blood samples from gilts were collected from the anterior vena cava at 2 to 3 days post partum and at weaning (on day 28 of lactation). Colostrum was collected by hand from all functional teats during the farrowing process. Milk samples were taken at weaning after an intravenous injection of 2 ml oxytocin (10 i.u. per ml) diluted with sterile sodium chloride solution (9 g/1000 ml) 1:1. Diets were sampled twice weekly during the experiment.

#### *Blood, milk and food analysis*

*Alpha-tocopherol.*  $\alpha$ -tocopherol content in the food, serum and milk was analysed in the Hoffmann - La Roche laboratory (Basle, Switzerland) using a high performance liquid chromatography (HPLC) method. The content of  $\alpha$ -tocopherol in food was analysed by the method of Manz and Philipp (1981) and serum, colostrum and milk according to the method described by Vuilleumier et al. (1983).

Table 2. Composition and nutrient content of diets

Composition (g/kg)	Diet 1 <sup>a</sup>	Diet 2 <sup>b</sup>
Wheat middlings	158	148
Maize gluten feed	150	150
Soya-bean meal	180	182
Tapioca meal	297	320
Alfalfa meal	90	75
Molasses, beet	50	50
DL-methionine	0.4	0.4
Monocalcium phosphate	9	9
Salt	3.8	3.8
Vitamin/mineral pre-mix <sup>c</sup>	5	5
Limestone	6.8	6.8
Sunflower oil	50	-
Animal fat	-	50
Nutrient content:		
as analysed (g/kg DM)		
Crude protein	178	175
Crude fat	71	75
Crude fibre	66	64
as calculated		
Metabolizable energy <sup>d</sup> , MJ/kg DM	14.30	14.29
Digestible lysine, g/kg DM	7.44	7.33

<sup>a</sup> For treatments 1, 2, 3.

<sup>b</sup> For treatments 4, 5, 6.

<sup>c</sup> Basal pre-mix contains (per kg): calcium 284 g, copper 2000 mg, manganese 4800 mg, zinc 8000 mg, iron 16000 mg, cobalt 50 mg, iodine 80 mg, selenium 20 mg, all-trans-retinyl acetate 482 mg, cholecalciferol 7 mg, riboflavin 800 mg, niacin 3600 mg, D-pantothenic acid 1400 mg, choline 50000 mg, cyanocobalamin 3 mg, DL-alpha-tocopheryl acetate 2400 mg, biotin 20 mg.

<sup>d</sup> Calculated from net energy according to Centraal Veevoederbureau (CVB, 1988) and assuming net energy is 0.7 of metabolizable energy.

**Cell isolation.** Peripheral blood lymphocytes were isolated using density centrifugation as described by Miller (1986).

**Lymphocyte stimulation test (LST).** The mitogen responsiveness of lymphocytes to concanavaline A (ConA) was determined with LST using the method of Joling et al. (1983). Proliferation of lymphocytes was measured using <sup>3</sup>H-thymidine incorporation and the results were expressed as counts per minute (c.p.m.).

**Lysozyme activity.** This was measured in blood as described by Lie (1980).

**Quantification of B- and T-lymphocytes.** Partition of blood lymphocytes into B-lymphocytes and T-lymphocytes was determined with a fluorescence staining technique. Analysis of B-lymphocytes was

performed using rabbit anti-swine Ig (RASwIg) conjugated with fluorescence isothiocyanate (FITC). T-lymphocytes were recognized by their CD2 surface molecule using monoclonal antibody MSA4 (Hammerberg and Schurig, 1986). Cells were incubated with an optimal dilution of antibody i.e.  $10^6$  cells in a volume of 40  $\mu$ l of colour medium existing of RPMI-1640 medium supplemented with 20 ml/ l foetal calf serum (FCS) and 1 g/l of natriumazide. After 30 min at 0°C the cells were washed in the same medium. Cells stained with CD2 were cultured with second step antibody consisting of FITC-conjugated goat anti-mouse Ig antibody (F-GAM) under the same conditions as the first incubation step. Subsequently, the cells were washed and analysis was carried out with the fluorescence-activated cell sorter (FACStar, Becton and Dickinson, USA) equipped with a 5-W argon-ion UV/vision laser. Forward light scatter windows were set to exclude erythrocytes and dead cells and analysis of the cell distribution was performed by computer program (Consort-30, Becton and Dickinson, USA).

**Single radial immunodiffusion (SRID).** Concentrations of IgG, IgA and IgM were assayed in serum as well as in colostrum and milk. The technique was used as described by Mancini et al. (1965). In short: agarose gels (10 g/l) in barbitane buffer (pH 8.2) were mixed with anti-isotype sera (56 °C): goat anti-swine IgG (GASwIgG), GASwIgM and GASwIgA (Kirkegaard and Perry Laboratories Inc. USA). Samples were diluted in 9 g/l NaCl and injected in punched holes in the gel. Positive reactions correlated with precipitation, which reflects with the concentration of the isotypes. The relative values were calculated by the formula:

$$rv = r^2_{\text{sample}} / r^2_{\text{standard}}$$

where: rv = relative value; r = radial of precipitation ring (mm).

**Food analysis.** Analysis of dry matter, nitrogen and crude fat were performed according to International Standards Organization: ISO 6496 (1983), ISO 5983 (1979) and ISO 6492 (1985), respectively. Crude fibre was analysed by Dutch standard (Nederlands Normalisatie-Instituut: NEN 5417, 1988).

#### Statistical analysis

Data per sampling day were analysed by the following model:

$$Y_{ijkl} = \mu + A_i + B_j + (AB)_{ij} + C_k + e_{ijkl}$$

in which:  $Y_{ijkl}$  = dependent variable;  $\mu$  = mean;  $A_i$  = type of dietary fat ( $i = 1, 2$ );  $B_j$  =  $\alpha$ -tocopherol level in sow's diet ( $j = 1, 2, 3$ );  $(AB)_{ij}$  = interaction between fat and  $\alpha$ -tocopherol;  $C_k$  = batch ( $k = 1, 2$ );  $e_{ijkl}$  = residual error.

Analysis of variance were used by GLM procedure from the Statistical Analysis Systems Institute (SAS, 1985). When interaction and batch were not significant, the model was recalculated then without these variables. Data were tested at a 0.05 probability level. When a positive F test was obtained, differences among the means were examined by the Tukey-test (using SAS-GLM, SAS, 1985).

## Results and Discussion

### *Alpha-tocopherol concentration in serum, colostrum and milk*

Results for serum- colostrum- and milk  $\alpha$ -tocopherol content are summarized in Table 3.

**Table 3. Alpha-tocopherol concentration in serum, colostrum and milk**

Item	Treatment (Code) <sup>a</sup>						RMSE <sup>b</sup>
	1(LV)	2(MV)	3(HV)	4(LA)	5(MA)	6(HA)	
Serum, mg/l							
Post partum	1.50 <sup>d</sup>	1.63 <sup>d</sup>	2.35 <sup>c</sup>	0.72 <sup>e</sup>	1.30 <sup>d</sup>	2.25 <sup>c</sup>	0.28
At weaning	2.47 <sup>d</sup>	2.03 <sup>d</sup>	3.60 <sup>c</sup>	0.97 <sup>e</sup>	1.97 <sup>d</sup>	3.43 <sup>c</sup>	0.50
Colostrum							
mg/kg	24.04 <sup>cd</sup>	25.21 <sup>cd</sup>	28.61 <sup>c</sup>	12.27 <sup>d</sup>	26.38 <sup>cd</sup>	38.69 <sup>c</sup>	7.86
$\mu$ g/g fat	334.10 <sup>d</sup>	392.52 <sup>d</sup>	449.10 <sup>d</sup>	182.42 <sup>e</sup>	428.87 <sup>d</sup>	593.20 <sup>c</sup>	71.31
Milk							
mg/kg	3.30 <sup>d</sup>	4.98 <sup>c</sup>	4.94 <sup>c</sup>	1.13 <sup>e</sup>	2.49 <sup>d</sup>	4.49 <sup>c</sup>	0.67
$\mu$ g/g fat	45.64 <sup>cd</sup>	47.89 <sup>cd</sup>	65.97 <sup>c</sup>	13.91 <sup>e</sup>	30.33 <sup>de</sup>	64.50 <sup>c</sup>	13.00

<sup>a</sup> Treatments and codes are defined in Table 1.

<sup>b</sup> Root mean square error.

<sup>c,d,e</sup> Different superscripts in the same row indicate significant differences among treatments ( $P < 0.05$ ).

Results show that the  $\alpha$ -tocopherol content in serum of the sows just after farrowing in both fat groups was increased by dietary  $\alpha$ -tocopherol intake but at the low dietary level of  $\alpha$ -tocopherol (L) the content was significantly higher for the sunflower oil-based diet than for the animal fat-based diet ( $P < 0.05$ ). At weaning a similar trend was observed. The sows given a high level (H) of  $\alpha$ -tocopherol during gestation and lactation had the highest serum  $\alpha$ -tocopherol concentration during the suckling period on both fat diets ( $P < 0.05$ ). This was an  $\alpha$ -tocopherol and fat effect, because the daily food intake during lactation in all treatment groups was similar (mean: 4.6 kg per sow; range: 4.4 to 4.7 kg per sow).

Loudenslager et al. (1986) reported that sows given  $\alpha$ -tocopherol and selenium- supplemented diets had significantly increased plasma levels of both  $\alpha$ -tocopherol and selenium in late gestation and also

during lactation. Malm et al.(1976) also found that serum  $\alpha$ -tocopherol concentration of sows post partum and at 3 weeks of lactation was significantly reduced with low dietary  $\alpha$ -tocopherol . This level was slightly increased in diets containing lard plus  $\alpha$ -tocopherol than with maize oil plus  $\alpha$ -tocopherol. Results of their investigation thus suggest a trend for a sustained difference in favour of the lard plus  $\alpha$ -tocopherol, which contradicts the results of our study. However, it should be noted that Malm et al. (1976) gave food to their sows ad libitum during lactation. In the present study, the serum  $\alpha$ -tocopherol between gilts given animal fat containing high  $\alpha$ -tocopherol, compared with sunflower oil plus high dietary  $\alpha$ -tocopherol did not differ significantly ( $P > 0.05$ ).

Results for  $\alpha$ -tocopherol content of colostrum and milk are also presented in Table 3. The  $\alpha$ -tocopherol in colostrum (mg/kg) was increased as dietary levels of  $\alpha$ -tocopherol during pregnancy were increased. The increase in the sunflower oil groups was less than in the animal fat groups. It can be seen also that there was a pronounced decrease in  $\alpha$ -tocopherol concentration in milk during lactation (4 weeks) as evidenced by the data obtained at weaning. However, in milk, increasing concentrations of dietary  $\alpha$ -tocopherol did increase with concentrations of  $\alpha$ -tocopherol particularly in those sows given the animal fat diets.

In colostrum fat the  $\alpha$ -tocopherol level ( $\mu\text{g} / \text{g}$  milk fat) in the high  $\alpha$ -tocopherol group with animal fat differed from all other groups ( $P < 0.05$ ). At the end of lactation in both the sunflower oil and animal fat groups a tendency for an increase in the  $\alpha$ -tocopherol content was observed from the higher dietary  $\alpha$ -tocopherol content. The data demonstrate that a high level of dietary  $\alpha$ -tocopherol with animal fat during gestation had a greater effect on concentrations of colostrum  $\alpha$ -tocopherol than with sunflower oil. At the end of lactation this clear difference between HV and HA group was not observed. In several studies, it has been shown that the  $\alpha$ -tocopherol content of sow's milk was increased with extra dietary  $\alpha$ -tocopherol (Cline et al., 1974; Young et al., 1977) and that the supplementation of the sow's diet with  $\alpha$ -tocopherol and selenium could maintain high tocopherol and selenium levels in colostrum and milk during lactation (Loudenslager et al., 1986). These trends were also observed in our study, especially in the animal fat group. Chavez and Patton (1986), however, reported that the  $\alpha$ -tocopherol content in colostrum was not affected after injection of  $\alpha$ -tocopherol and selenium. In the current study a pronounced decrease in  $\alpha$ -tocopherol concentration during lactation was found in all treatment groups. Similar trends were obtained by Malm et al. (1976). They also found that the concentration of  $\alpha$ -tocopherol in colostrum and milk fat was six to 35 times higher in sows given supplemental dietary  $\alpha$ -tocopherol than without. Animal fat from lard tended to promote a higher concentration of  $\alpha$ -tocopherol than maize oil but the difference was not significant.

*Immunological variables*

*Leucocyte values and T-lymphocytes.* Data are given in Table 4. No significant differences were found for leucocyte counts between  $\alpha$ -tocopherol or fat groups after farrowing and at weaning. All means for total leucocyte numbers remained within the normal ranges (Calhoun and Brown, 1975).

**Table 4. Total leucocyte counts ( $\times 10^6/\text{ml}$ ), percentage of T-lymphocyte (CD2 cells) in blood of sows**

Item	Treatment (code) <sup>a</sup>					RMSE <sup>b</sup>
	Vitamin E			Fat		
	L	M	H	V	A	
<b>Leucocyte</b>						
Post partum	11.0	13.3	13.4	13.0	12.2	3.81
At weaning	12.4	11.6	13.7	11.8	13.4	4.37
<b>T-lymphocyte</b>						
Post partum	53.9	55.7	52.2	54.0	53.9	9.50
At weaning	63.7	67.5	63.9	64.5	65.5	9.77

<sup>a</sup> Treatments and codes are defined in Table 1.

<sup>b</sup> Root mean square error.

It therefore appears that neither dietary  $\alpha$ -tocopherol intake nor fat source affect leucocyte numbers. Niyo et al. (1980) also found a similar effect on leucocyte count between tocopherol-deficient and tocopherol-supplemented (injected intramuscularly) piglets during the suckling and rearing periods. Nafstad (1965), however, noted higher leucocyte counts in deficient pigs than in supplemented animals.

No differences were found between  $\alpha$ -tocopherol or fat groups post partum or at weaning in the percentages of T-lymphocytes. During lactation a small increase was observed in all treatment groups. The present data suggest that the percentage of T-cells in sow blood was not affected by dietary  $\alpha$ -tocopherol or by the fat source.

In the current investigation data on LST-test indicated that in lactating sows neither the percentage of T-cells nor the stimulation of T-lymphocytes was influenced by dietary  $\alpha$ -tocopherol supplementation or by dietary fat type (range of incorporation of <sup>3</sup>H-thymidine in treatment groups: after farrowing: 25 000 to 57 000 c.p.m.; at weaning: 31 000 to 56 000 c.p.m.). These results may indicate that for the conditions applied no deficiency could be observed to the mitogen responsiveness.

**Concentration of lysozyme in blood.** Differences among all treatments after farrowing and at weaning were not significant (data not shown). On the basis of these results it appears that the phagocyte capacity of leucocytes in lactating sows was not affected by different levels of dietary  $\alpha$ -tocopherol or by different types of dietary fat.

**Percentage of B-lymphocytes.** It can be seen from Figure 1a that after farrowing the percentage of B-lymphocytes was not affected by different  $\alpha$ -tocopherol levels ( $P > 0.05$ ). The sunflower oil group showed a higher value for B-lymphocytes than the animal fat group ( $P < 0.05$ ). At the end of lactation (Figure 1b) some increase in B-lymphocytes was found with increasing  $\alpha$ -tocopherol intake ( $P > 0.05$ ). In the vegetable fat group the value was still higher ( $P < 0.05$ ) than in the animal fat group. The present data on B-lymphocytes may indicate that the humoral immune status of sows was slightly affected by dietary  $\alpha$ -tocopherol only at weaning. During lactation the vegetable fat had a greater effect on the percentage of B-lymphocytes than the animal fat.

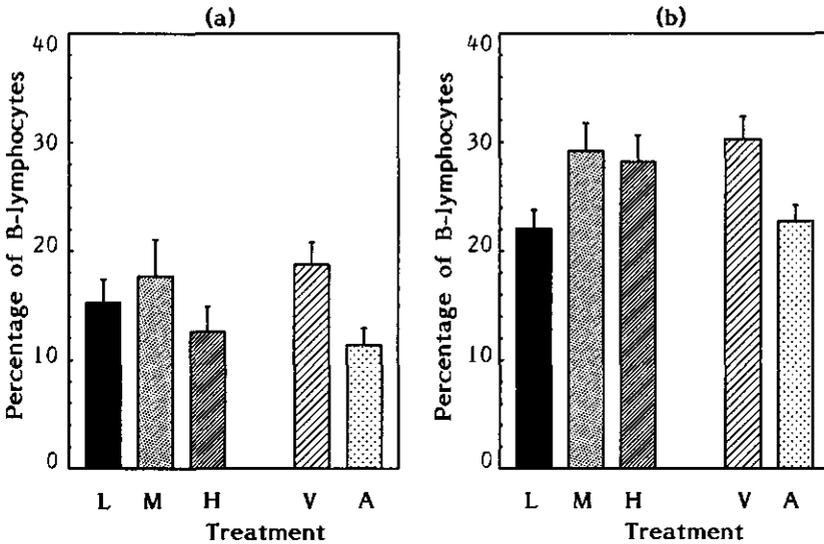
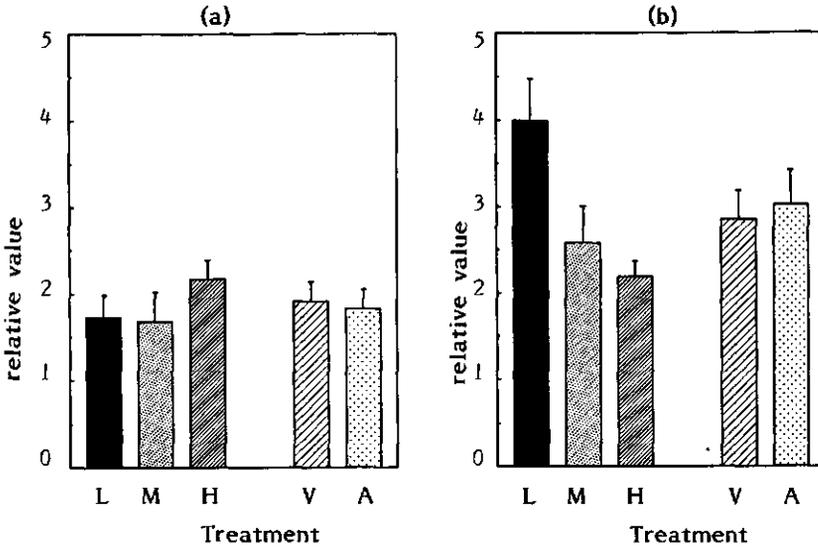


Figure 1. Mean percentage (with s.e.) of B-lymphocytes in blood from sows by different levels of dietary  $\alpha$ -tocopherol (L, M, H) and fat source (V, A) (a) post partum and (b) at weaning. Treatments and codes are same as stated in Table 1.

**Serum immunoglobulin concentrations.** Data on serum IgG levels as treatment means are presented in Figure 2. After farrowing (Figure 2a) neither an  $\alpha$ -tocopherol nor a fat effect was observed ( $P > 0.05$ ). At the end of lactation (Figure 2b) a pronounced decrease of IgG concentration was found from increased dietary  $\alpha$ -tocopherol intake. The IgG concentration in group H was lower ( $P < 0.05$ ) than in group L. Fat source had no effect on serum IgG concentration.



**Figure 2.** Mean IgG concentration (with s.e.) in serum from sows by different levels of dietary  $\alpha$ -tocopherol (L, M, H) and fat source (V, A) (a) post partum and (b) at weaning.

Treatments and codes are same as stated in Table 1.

Nockels (1986) and Pharazyn et al. (1990) reported increased antibody production in animals after supplementation with  $\alpha$ -tocopherol. Our data suggest that there exists a discrepancy between specific antibody production and the total immune globulin titres with regard to  $\alpha$ -tocopherol supplementation. Hayek et al. (1989) found that in sows the serum IgG concentration decreased sharply around farrowing in all groups (treatments plus control) and increased during the first 2 weeks of lactation. At week 4 of lactation serum IgG concentration was somewhat lower in the  $\alpha$ -tocopherol treated group than in the control. They suggested that the sows already had well-developed immunoglobulin levels and their blood concentrations were not consistently affected by treatments.

The relative IgM values showed that the IgM content was not affected by dietary  $\alpha$ -tocopherol or fat source (data not shown). The concentration of IgA in serum (and also IgA and IgM in colostrum and milk) were below the detection level of the SRID technique.

It appears that at the end of lactation in the current study the higher percentage of B-lymphocytes was related to decreased levels of serum IgG as shown in Figures 1b and 2b. When B-lymphocyte activation is followed by transformation to the antibody producing plasma cells this latter cell type may provide a better expression of serum Ig. Another explanation for the observed discrepancy could be a regulatory effect of  $\alpha$ -tocopherol on the direction of the immune response. Increased cellular reactivity after a high  $\alpha$ -tocopherol supplementation has been reported by Nockels (1986) which could explain decreased levels of the total antibody production. Further experiments must elucidate such an effect of  $\alpha$ -tocopherol on the humoral immune system.

**Immunoglobulin concentration in colostrum and milk.** The relative values of IgG in colostrum and milk (before weaning) are shown in Table 5. IgG in colostrum was somewhat higher with the HA group

**Table 5. IgG in colostrum and milk (relative values by SRID-test)<sup>a</sup>**

Item	Treatment (code) <sup>b</sup>					RMSE <sup>c</sup>
	Vitamin E			Fat		
	L	M	H	V	A	
Colostrum	4.61	3.69	4.94	4.07	4.75	1.28
Milk at weaning	0.16 <sup>d</sup>	0.17 <sup>d</sup>	0.12 <sup>e</sup>	0.15	0.14	0.04

<sup>a</sup> Single radial immunodiffusion.

<sup>b</sup> Treatments and codes are defined in Table 1.

<sup>c</sup> Root mean square error.

<sup>d,e</sup> Different superscripts in the same row indicate significant differences among treatments ( $P < 0.05$ ).

( $P > 0.05$ ). At the end of lactation the lowest values of IgG in milk were found in sows with the highest dietary  $\alpha$ -tocopherol level ( $P < 0.05$ ), a response similar to that recorded for serum IgG concentrations. The fat source had no influence on IgG content in milk.

Hayek et al. (1989) found that colostrum IgG and IgA concentration were not affected by injection with  $\alpha$ -tocopherol and/or selenium but that injections of selenium resulted in higher colostrum IgM levels.

**Conclusions.** A high  $\alpha$ -tocopherol level in a sow's gestation diet, including either sunflower oil or animal fat increased the serum  $\alpha$ -tocopherol concentration after farrowing. At a low  $\alpha$ -tocopherol level significantly higher concentrations were found for the sunflower oil than for the animal fat ( $P < 0.05$ ). The high  $\alpha$ -tocopherol intake during lactation in both fat groups resulted in higher serum  $\alpha$ -tocopherol concentration ( $P < 0.05$ ). In the animal fat groups with an increase of  $\alpha$ -tocopherol in the diet, the colostral  $\alpha$ -tocopherol was also increased ( $P < 0.05$ ). At weaning this trend was clearer in the animal fat group than in the sunflower oil group. In animals given low  $\alpha$ -tocopherol and animal fat the serum, colostrum and milk  $\alpha$ -tocopherol concentration was low ( $P < 0.05$ ).

The cell-mediated immunity and the phagocytic capacity of sows were not systematically affected by  $\alpha$ -tocopherol supplementation or by different types of dietary fat. However, the humoral immune system may have been affected by the combinations of  $\alpha$ -tocopherol and fat which were used (Figure 1).

## References

- Adams, C.R. and C.R. Zimmerman. 1982. Many factors affect pigs' vitamin E needs. *Feedstuffs* 24: 30-31.
- Agricultural Research Council. 1981. *The Nutrient Requirements of Pigs*. Commonwealth Agricultural Bureaux, Slough.
- Calhoun, M.L. and E.M. Brown. 1975. Hematology and hematopoietic organs. In *Diseases of Swine* (ed. H. W. Dunne and A. D. Leman), pp. 38-71. The Iowa State University Press, Ames, Ia.
- Centraal Veevoederbureau in Nederland (CVB). 1988. [*Dutch Feeding Tables*.] Centraal Veevoederbureau, The Netherlands.
- Chavez, E.R. and K.L. Patton. 1986. Response to injectable selenium and vitamin E on reproductive performance of sows receiving a standard commercial diet. *Can. J. Anim. Sci.* 66: 1065-1074.
- Cline, J.H., D.C. Mahan and A.L. Moxon. 1974. Progeny effects of supplemental vitamin E in sow diets. *J. Anim. Sci.* 39: 974 (Abstr.).
- Hammerberg, C. and G.G. Schurig. 1986. Characterization of monoclonal antibodies directed against swine leukocytes. *Vet. Immunol. Immunopathol.* 11: 107-121.
- Hayek, M.G., G.E. Mitchell, R.J. Harmon, T.S. Stahly, G.L. Cromwell, R.E. Tucker and K.B. Barker. 1989. Porcine immunoglobulin transfer after parturition treatment with selenium or vitamin E. *J. Anim. Sci.* 67: 1299-1306.
- International Standards Organization. 1983. *Animal feeding stuffs: Determination of moisture content*. (ISO 6496). 1979. *Determination of nitrogen content and calculation of crude protein content*. (ISO 5983). 1985. *Determination of fat by extraction*. (ISO 6492).
- Joling, P., L.M.B. Vaessen and J. Rozing. 1983. A two-gene control and responder mechanism regulating PHA responsiveness in rats. *Transplant. Proc.* 15: 1616-1619.
- Lie, Ø. 1980. Genetic variation in the serum lysozyme activity in cattle. *Acta Vet. Scand.* 21: 448-450.
- Loudenslager, M.J., P.K. Ku, P.A. Whetter, D.E. Ullrey, C.K. Whitehair, H.D. Stowe and E.R. Miller. 1986. Importance of diet of dam and colostrum to the biological antioxidant status and parenteral iron tolerance of the pig. *J. Anim. Sci.* 63: 1905-1914.
- Malm, A., W.G. Pond, E.F. Walker, M. Homan, A. Aydin and D. Kirtland. 1976. Effect of polyunsaturated fatty acids and vitamin E level of the sow gestation diet on reproductive performance and on level of alpha tocopherol in colostrum, milk and dam and progeny blood serum. *J. Anim. Sci.* 42: 393-399.
- Mancini, G., O. Carbonara and J.F. Heremans. 1965. Immunochemical quantitation of antigens by single radial immunodiffusion. *Immunochemistry* 2: 235-254.
- Manz, U. and K. Philipp. 1981. A method for the routine determination of tocopherols in animal feed and human foodstuffs with the aid of high performance liquid chromatography. *Int. J. Vitam. Nutr. Res.* 51: 342-348.
- Miller, R. G. 1986. Physical methods for separation of lymphocyte subpopulations. In: *Handbook of Experimental Immunology* (ed. D.M. Weir, C. Blackwell, L.A. Herzenberg and L.A. Herzenberg), pp. 54.1. Blackwell Scientific Publications, Oxford.
- Nafstad, I. 1965. Studies of hematology and bone marrow morphology in vitamin E-deficient pigs. *Path. Vet.* 2: 277-287.
- Nederlands Normalisatie-Instituut. 1988. [*Cereals, pulses and animal feeding stuffs. Determination of crude fibre content by abbreviated method.*] (NEN 5417).
- Niyo, Y., R.D. Glock, A.E. Ledet, F.K. Ramsey and R.C. Ewan. 1980. Effects of intramuscular injections of selenium and vitamin E on peripheral blood and bone marrow of selenium-vitamin E deficient pigs. *Am. J. Vet. Res.* 41: 474-478.
- Nockels, C. F. 1983. Vitamin E increases disease resistance. *Pig News and Inform.* 4: 289-291.
- Nockels, C. F. 1986. Nutrient modulation of the immune system. In: *Recent Advances in Animal Nutrition 1986*. (ed. W. Haresign and D.J.A. Cole), pp. 177-192. Butterworths, London.

- Pharazyn, A., L.A. den Hartog and F.X. Aherne. 1990. Vitamin E and its role in the nutrition of the gilt and sow: a review. *Livest. Prod. Sci.* 24: 1-13.
- Putnam, M. E. 1982. Vitamin E for pigs. *Pigs Vet. Soc. Proc.* 9: 178-183.
- Statistical Analysis Systems Institute. 1985. *SAS, User's Guide: Statistics*. Statistical Analysis Systems Institute, Cary, NC.
- Tengerdy, R. P., R.H. Heinzerling and C.F. Nockels 1972. Effect of vitamin E on the immune response of hypoxic and normal chickens. *Infect. Immun.* 5: 987-989.
- Ullrey, D. E. 1981. Vitamin E for swine. *J. Anim. Sci.* 53: 1039-1056.
- Vuilleumier, J. P., H.E. Keller, D. Gysel and F. Hunziker. 1983. Clinical chemical methods for routine the assessment of the vitamin status in human populations. Part I. The fat-soluble vitamins A and E, and  $\beta$ -carotene. *Int. J. Vit. Nutr. Res.* 53: 265-272.
- Young, L. G., R.B. Miller, D.E. Edmeades, A. Lun, G.C. Smith and G.J. King. 1977. Selenium and vitamin E supplementation of high moisture corn diets for swine reproduction. *J. Anim. Sci.* 45: 1051-1060.

## Chapter 6

**Effect of vitamin E and fat source in sows' diets on immune response of suckling and weaned piglets**

L. Babinszky<sup>1,4</sup>, D.J. Langhout<sup>1</sup>, M.W.A. Verstegen<sup>1</sup>, L.A. den Hartog<sup>3</sup>, P. Joling<sup>2</sup>,  
and M. Nieuwland<sup>2</sup>

<sup>1</sup> Department of Animal Nutrition, Agricultural University Wageningen, Haagsteeg 4, 6708 PM Wageningen, The Netherlands

<sup>2</sup> Department of Animal Husbandry, Agricultural University Wageningen, Marijkeweg 40, 6709 PG Wageningen, The Netherlands

<sup>3</sup> Research Institute for Pig Husbandry, P.O.Box 83, 5240 AB Rosmalen, The Netherlands

<sup>4</sup> Research Institute for Animal Nutrition, H-2053 Herceghalom, Hungary

## Effect of vitamin E and fat source in sows' diets on immune response of suckling and weaned piglets

### Abstract

Thirty-six 7-month-old gilts were used to study the effects of dietary vitamin E and fat source (5% sunflower oil or animal fat) in pregnant and lactating sow diets on serum vitamin E concentration and on cell-mediated and humoral immune response in suckling and weaned piglets. Six gilts each received one of six diets throughout pregnancy and lactation. The basal diets (13 mg  $\alpha$ -tocopherol/kg diet) were supplemented with DL- $\alpha$ -tocopheryl acetate to 48 and 136 mg  $\alpha$ -tocopherol/kg of feed (average analyzed values). After weaning (at 4 weeks of age) all pigs received identical diets (20 mg of  $\alpha$ -tocopherol/kg feed). One week after weaning, pigs were immunized (i.m. with ovalbumin and tetanus toxoid) and antibody production was measured. Blood samples were taken immediately after birth, at 1 week after birth, at weaning and at four weekly intervals after weaning. Samples were analyzed for  $\alpha$ -tocopherol concentration, total number of leukocytes, T- and B-lymphocytes, lymphocyte stimulation with concanavalin A, lysozyme activity, and immunoglobulin concentrations. It was concluded that a high vitamin E level in the sow's diet increased serum vitamin E concentration of 1-week-old pigs ( $P < 0.05$ ). Immune response against ovalbumin was increased ( $P < 0.05$ ) at 1 week of age after immunization for weaned pigs from sows fed the high level of vitamin E. Also, the phagocytic measures of pigs at 1 week of age were increased by the medium vitamin E level ( $P < 0.05$ ). Fat sources in the sow's diet had no consistent effect on the immunological measures of pigs.

**Key Words:** Vitamin E, Fat, Piglets, Suckling, Rearing, Immunity.

### Introduction

Vitamin E [vit. E] is associated with functions of the reproductive, nervous, circulatory, muscular and immune systems (Ullrey, 1981; Whitehair and Miller, 1985; Nockles, 1986). It seems to be essential for optimum function of all mammalian cells. This is thought to be related to its antioxidant property (McMurray and Rice, 1982). Dietary content of polyunsaturated fatty acids increases the requirement of  $\alpha$ -tocopherol (Pharazyn et al., 1990). Vit. E can affect the immune status (Nockels, 1986). It has been demonstrated that the immune status of mice, chickens (Tengerdy et al., 1972, 1973), and weanling pigs (Peplowski et al., 1981) is enhanced by high dietary vit. E levels.

The first weeks are very critical in the life of pigs. They depend highly on antibodies through absorption of immunoglobulins from colostrum. After this stage of passive immunity, the active

immune system is initiated. Vit. E levels in colostrum and milk are increased when high levels of vit. E are fed during pregnancy and lactation (Malm et al., 1976). It is assumed that this influences the immune status of pigs during suckling and rearing.

The present experiment was designed to investigate the effect of vit. E and fat source in diets during pregnancy and lactation on serum  $\alpha$ -tocopherol concentration in pigs. Also, humoral and cell-mediated immune response of pigs during suckling and after weaning were measured.

## Materials and Methods

### *Animals.*

A total of 36 PIC (Pig Improvement Company, England) hybrid, first-litter, 7-month-old gilts and their progeny were used in two batches. Animals were bred with Great Yorkshire boars at the experimental unit of the Agricultural University.

### *Experimental Design and Diets.*

The experiment was designed with two different fat sources and three levels of vit. E in the sow's diet at nearly identical levels of energy in a 2 x 3 factorial arrangement (Table 1).

**Table 1. Experimental arrangement**

Treatment	Code <sup>a</sup>	Vitamin E <sup>b</sup> in sow diet, mg/kg feed	Fat source in sow diet
1	LV	12	sunflower oil
2	MV	45	sunflower oil
3	HV	132	sunflower oil
4	LA	14	animal fat
5	MA	50	animal fat
6	HA	140	animal fat

<sup>a</sup>Vitamin E level (as  $\alpha$ -tocopherol): L (low); M (medium); H (high). Dietary fat: V (vegetable fat); A (animal fat).

<sup>b</sup>Analysed values.

An unsaturated vegetable fat (V; sunflower oil; commercial cooking-oil) and a saturated animal fat (A; slaughtering waste, packing house by-product; Nederlandse Thermo-Chemische Fabrieken, The Netherlands) were used. These fats were included in the diet at a level of 5% (Table 2). The basal diets contained 13 mg  $\alpha$ -tocopherol /kg feed (low level)=L and these diets were supplemented by DL- $\alpha$ -tocopheryl acetate to 48 (medium level)=M and 136 (high level)=H mg of  $\alpha$ -tocopherol per kilogram

of feed (average analyzed values). The selenium concentration of diets was 0.1 mg per kilogram of feed.

**Table 2. Composition of diets for pregnant and lactating sows**

Ingredient, g/kg	Diet 1 <sup>a</sup>	Diet 2 <sup>b</sup>
Wheat middlings	158	148
Corn gluten feed	150	150
Soya-bean meal	180	182
Tapioca meal	297	320
Alfalfa meal	90	75
Molasses, beet	50	50
DL-methionine	0.4	0.4
Monocalcium phosphate	9	9
Salt	3.8	3.8
Vitamin/mineral pre-mix <sup>c</sup>	5	5
Limestone	6.8	6.8
Sunflower oil	50	-
Animal fat	-	50
Nutrient content:		
as analysed (g/kg DM)		
Crude protein	178	175
Crude fat	71	75
Crude fibre	66	64
as calculated		
Metabolizable energy <sup>d</sup> , MJ/kg DM	14.30	14.29
Digestible lysine, g/kg DM	7.44	7.33

<sup>a</sup> For treatments 1, 2, and 3.

<sup>b</sup> For treatments 4, 5, and 6.

<sup>c</sup> 1 kg of basal premix contains: calcium 284 g, copper 2000 mg, manganese 4800 mg, zinc 8000 mg, iron 16000 mg, cobalt 50 mg, iodine 80 mg, selenium 20 mg, all-trans-retinyl acetate 482 mg, cholecalciferol 7 mg, riboflavin 800 mg, niacin 3600 mg, D-pantothenic acid 1400 mg, choline 50000 mg, cyanocobalamin 3 mg, DL-alpha-tocopheryl acetate 2400 mg, biotin 20 mg.

<sup>d</sup> Calculated from net energy according to Centraal Veevoederbureau (CVB, 1988) and assuming net energy is 70% of metabolizable energy.

### **Feeding and Housing.**

The experiment was started at mating and lasted until the pigs were 8 weeks of age (4 weeks of suckling plus a subsequent period of 4 weeks for rearing).

Each sow received in each treatment during pregnancy and lactation a diet of the same composition.

During pregnancy the gilts were fed 30 MJ ME/d (2.4 kg.d<sup>-1</sup>.gilt<sup>-1</sup>) from d 21 after insemination

onward. During lactation sows received feed at a level of 1% of body weight (maintenance) and an additional 0.5 kg per pig (for milk).

During suckling no creep feed was given. Pigs were weaned at 28 d of lactation (range in age: 27 to 29 d). After weaning, pigs of all sows ate the same rearing diet (20 mg of  $\alpha$ -tocopherol/kg) ad libitum (Table 3).

The nutrient content of the diet was established according to the Dutch standard (CVB, 1988).

For each treatment group, six gilts were used. Animals were fed twice daily in individual feeding crates during pregnancy. On d 110 of gestation each gilt was moved to a farrowing crate. After weaning, pigs from various treatments were mixed and housed in groups of 10 animals each. Water was available ad libitum for sows and pigs during the whole experiment.

#### ***Blood, Milk and Feed Sampling.***

Blood samples from piglets were taken three times during suckling: immediately after birth (before colostrum intake), 1 week after birth, and at weaning (4 weeks of age). After weaning, animals were sampled four times at intervals of 1 week. Samples were taken by external jugular veni-puncture in vacuum tubes. Each time, blood from two pigs from each litter was sampled. During rearing each piglet was sampled a maximum of two times.

One week after weaning (average 5 weeks of age) all pigs were immunized intramuscularly with 4 mg of ovalbumin in 0.5 ml of 0.9 % NaCl and 0.5 ml incomplete Freund's adjuvant [Rijksinstituut voor de Volksgezondheid, Bilthoven, The Netherlands] (in one side of the neck) and with 0.33 ml of tetanus toxoid vaccine (10 Lf/ml, 3 mg/ml aluminum phosphate) in 0.67 ml of 0.9 % NaCl (in the other side of the neck) to measure antibody production at intervals of 7 days after injection. Blood sampling as well as immunization was done at specific intervals after birth. In the first batch of sows, pig sampling was done on a single day. In the second batch of sows, pigs were sampled on two separate days.

Colostrum was collected by hand from all functional nipples during the farrowing process (six sows per treatment). Milk samples were obtained at weaning using an intravenous injection of 2 ml of oxytocin (10 IU/ml) diluted with sterile NaCl solution (0.9%) 1:1.

Experimental diets were sampled two times per week during the experiment.

Table 3. Composition of diet for weaned pigs

Ingredient	g/kg
Barley	350
Linseed expeller	25
Cooked corn	92
Cooked wheat	226
Denatured skim milk powder	85
Delactosed whey powder	100
Potato protein	50
Formic acid	4
Coconut oil	4
Calprona-P <sup>a</sup>	5
Animal fat	18
Vegetable fat	13
Crystalline lysine and methionine <sup>b</sup>	6
Monocalcium phosphate	10
Limestone	2
Premix <sup>c</sup>	10
Nutrient content	
as analysed (g/kg DM)	
Crude protein	196
Crude fat	50
Crude fiber	31
as calculated	
Metabolizable energy <sup>d</sup> , MJ/kg DM	16.33
Digestible lysine, g/kg DM	13.90

<sup>a</sup> Mixture of propionic, formic, and acetic acid; Verdugt B.V, The Netherlands.

<sup>b</sup> 20% L-lysine and 10% DL-methionine.

<sup>c</sup> 1000 g of premix contains: copper 10000 mg, iron 2250 mg, zinc 12500 mg, manganese 4000 mg, cobalt 15 mg, iodine 40 mg, selenium 12.5 mg, all-trans-retinyl acetate 516 mg, cholecalciferol 5 mg, dl-alpha-tocopheryl acetate 2500 mg, riboflavin 400 mg, niacin 4000 mg, d-panthotenic acid 1500 mg, choline 8000 mg, folic acid 40 mg, cyanocobalamin 2 mg, ascorbic acid 25000 mg, vitamin K<sub>3</sub> 100 mg, Carbadox 5000 mg, L-lysine 200 g, DL-methionine 90 g.

<sup>d</sup> Calculated from net energy according to Centraal Veevoederbureau (CVB, 1988) and assuming net energy is 70 % of metabolizable energy.

### Blood, Milk, and Feed Analysis

**Alpha Tocopherol.** Alpha-tocopherol content in the feed, serum, and milk was analyzed using a HPLC method (F. Hoffmann- La Roche Laboratory, Basle, Switzerland). The dietary  $\alpha$ -tocopherol was analyzed by the method of Manz and Philipp (1981), and serum, colostrum, and milk were analyzed according to the method described by Vuilleumier et al. (1983).

**Cell Isolation.** Peripheral blood lymphocytes were isolated using density centrifugation as described by Miller (1986).

**Lymphocyte Stimulation Test.** The mitogen responsiveness of lymphocytes to concanavalin A (ConA) was determined with a lymphocyte stimulation test (LST) using the method of Joling et al. (1983).

**Quantification of B- and T-lymphocytes.** Composition of the blood lymphocyte population was measured using direct or indirect fluorescence staining techniques as described by Rozing et al. (1977) and analyzed on a fluorescence-activated cell sorter (FACStar, Becton-Dickinson, Oxnard, CA.). B-lymphocytes were labeled with rabbit anti-swine immunoglobulin conjugated with fluorescence isothiocyanate (Dako-Immunoglobulins, Denmark). T-lymphocytes were labeled with monoclonal antibody MSA4 directed against the CD2 surface molecule (Hammerberg and Schurig, 1986).

**Lysozyme Activity.** The lysozyme activity in blood was measured as described by Lie (1980).

**Single Radial Immunodiffusion.** Concentration of the isotypes were assayed in serum as well as in colostrum and milk as described by Mancini et al. (1965). Agarose gels (1 %) in barbitione buffer (pH 8.2) were mixed with anti-isotype sera. The anti-isotype sera used were goat anti-swine immunoglobulins (Ig) G, M and A (Kirkegaard and Perry Laboratories Inc., Gaithersburg, MD.). Samples were diluted in 0.9 % NaCl and injected in punched holes in the gel. Positive reactions correlated with precipitation, which reflects the concentration of the isotypes. The relative values were calculated by the following formula:

$$rv = r^2_{\text{sample}} / r^2_{\text{standard}}$$

where: rv= relative value and r = radial of precipitation ring (mm).

**Enzyme-Linked Immunosorbent Assay.** Specific antibody response directed against ovalbumin and tetanus toxoid was measured using a direct ELISA technique (Van Zaane and Hulst, 1987). Antigen (ovalbumin, 10 µg/ml; tetanus toxoid, 10 Lf/ml) was dissolved in coating buffer (carbonate buffer, pH 9.6). For each test at least four serum dilutions in 0.15 M PBS (pH 7.2) containing 2 % NCS and 0.05 % of Tween-20 (Brocacef, The Netherlands) were used. After incubation for 2 h at 37°C, the bound antibody could be determined with rabbit anti-swine IgG conjugated peroxidase (Nordic Immunology, The Netherlands). Peroxidase activity could be measured with the help of tetramethyl benzidine in a concentration of 6 mg/ml dissolved in desoxymethylsulfoxide. The extinction was measured at 450 nm.

#### **Feed Analysis.**

Analysis of dry matter, nitrogen and crude fat were done according to procedures outlined by the International Organization for Standardization (ISO 6496 [1983], ISO 5983 [1979], and ISO 6492 [1985] respectively). Crude fiber was analyzed by Dutch standard (NEN 5417, 1988).

**Statistical Analysis.**

Data were analyzed by ANOVA with the following models per sampling day. Colostrum and milk from sows was analyzed using the following model:

$$Y_{ijkl} = \mu + A_i + B_j + (AB)_{ij} + C_k + e_{ijkl} \quad [1]$$

where:  $Y_{ijkl}$  = dependent variable,  $\mu$  = mean,  $A_i$  = type of dietary fat ( $i = 1, 2$ ),  $B_j$  = vit. E level in sows' diet ( $j = 1, 2, 3$ ),  $(AB)_{ij}$  = interaction between fat and vit.E,  $C_k$  = batch of sows ( $k = 1, 2$ ), and  $e_{ijkl}$  = residual error.

When interaction and batch of sows were not significant, the model was recalculated without these variables. For blood samples from pigs, the following model was used:

$$Y_{ijklm} = \mu + A_i + B_j + (AB)_{ij} + C_k + D_l + e_{ijklm} \quad [2]$$

where:  $Y_{ijklm}$  = dependent variable,  $\mu$  = mean,  $A_i$  = type of dietary fat in sow's diet ( $i = 1, 2$ ),  $B_j$  = vit.E level in sow's diet ( $j = 1, 2, 3$ ),  $(AB)_{ij}$  = interaction between fat and vit.E,  $C_k$  = blood sampling group of piglets ( $k = 1, 2, 3$ ),  $D_l$  = mean size of litter during lactation, and  $e_{ijklm}$  = residual error.

Analysis of variance was done by GLM procedure (SAS, 1985) for both milk and blood values. When significant effects were obtained with models [1] and [2], differences between means were compared by Tukey's test (SAS, 1985). Data were tested at a 0.05 significance level. Interactions or effects of blood sampling group and litter size (model [2]) were omitted if not significant. In model [2], sow effect was not found. Variation between pigs within sow was similar to variation between pigs between sows within treatment.

In the present study, data on colostrum and milk represent the mean of six observations. However, data on blood measures in pigs represent the mean of 10 to 12 samples per vit. E and fat combination, or 21 to 24 samples per vit. E level in the sow's diet.

**Results*****Alpha Tocopherol Concentrations***

***Colostrum and Milk Samples.*** Because vit. E is a fat-soluble vitamin,  $\alpha$ -tocopherol (vit. E) concentrations are presented as micrograms per gram of fat. In the sows fed sunflower oil, added vit. E had no effect on vit. E level in colostrum fat and in milk fat (Table 4). In combination with animal fat, there was an increase ( $P < 0.05$ ) in vit. E content in colostrum and milk when higher levels of vit.

**Table 4. Effect of dietary vitamin E and fat source on alpha tocopherol concentration in colostrum and milk<sup>a</sup>**

Item	Treatment (Code) <sup>b</sup>						RMSE <sup>c</sup>
	1(LV)	2(MV)	3(HV)	4(LA)	5(MA)	6(HA)	
Colostrum	334 <sup>e</sup>	392 <sup>e</sup>	449 <sup>e</sup>	182 <sup>f</sup>	429 <sup>e</sup>	593 <sup>d</sup>	71
Milk	46 <sup>de</sup>	48 <sup>de</sup>	66 <sup>d</sup>	14 <sup>f</sup>	30 <sup>ef</sup>	64 <sup>d</sup>	13

<sup>a</sup> All concentrations of  $\alpha$ -tocopherol expressed as micrograms per gram of fat.

<sup>b</sup> Treatments and codes are defined in Table 1.

<sup>c</sup> Root mean square error.

<sup>d,e,f</sup> Different superscripts in the same row indicate significant differences among treatments ( $P < 0.05$ )

E were included in the diet. In both colostrum and milk the lowest values were measured in gilts fed animal fat and the low vit. E level. During lactation, a pronounced decrease in vit. E concentration was observed in all groups.

**Blood Samples From Pigs.** The serum vit. E concentration just after birth in groups fed either sunflower oil or animal fat tended to be higher ( $P > 0.05$ ) when sows were fed high vit. E levels (Table 5).

**Table 5. Effect of dietary vitamin E and fat source in the sow's diet on serum alpha tocopherol concentration in pigs<sup>a</sup>**

Age, week	Treatment (Code) <sup>b</sup>						RMSE <sup>c</sup>
	1(LV)	2(MV)	3(HV)	4(LA)	5(MA)	6(HA)	
0 <sup>d</sup>	0.19	0.15	0.21	0.08	0.13	0.17	0.07
1	4.74 <sup>f</sup>	4.56 <sup>f</sup>	6.36 <sup>e</sup>	3.33 <sup>f</sup>	5.27 <sup>f</sup>	6.43 <sup>e</sup>	1.68
4 <sup>e</sup>	2.48	2.69	3.31	1.60	2.53	1.93	1.34
8	0.92	0.96	0.85	0.58	0.63	0.74	0.27

<sup>a</sup> All concentrations of  $\alpha$ -tocopherol are expressed as milligrams per liter.

<sup>b</sup> Treatments and codes are defined in Table 1.

<sup>c</sup> Root mean square error.

<sup>d</sup> Just after birth, before colostrum intake.

<sup>e</sup> Weaning.

<sup>f,g</sup> Different superscripts in the same row indicate significant differences among treatments ( $P < 0.05$ ).

Vit. E levels in blood serum at 1 week of age were increased ( $P < 0.05$ ) in both fat groups by high vit. E levels in the sow's diet. At weaning the serum vit. E concentration was not affected by vit. E levels

in the sow diet. However, in the groups fed sunflower oil, higher ( $P < 0.05$ ) values were measured than in the groups fed animal fat. At the end of rearing there was no treatment effect observed. During the experiment the lowest values were obtained just after birth and the highest at 1 week of age. In this table it also can be seen that the lowest vit. E concentrations during the experiment were measured in pigs from sows fed low vit. E with animal fat.

#### *Immunological Parameters in Pigs*

**Cell Isolation.** Treatments had no effect on the total number of leukocytes and on the mitogen response to ConA during the suckling and rearing periods (data not shown).

**Quantification of T- and B-lymphocytes.** The least squares means of T-lymphocyte percentage between treatments 1 to 6 at 1 week of age ranged between 25 and 52%, at 4 weeks of age between 55 and 63%, and at 7 weeks of age between 51 to 54%. In several animals, isolation of lymphocytes at 1 week of age was problematic, so these animals were not tested. At 1 week of age the lowest value (25%,  $n=8$ ) was found in the sunflower oil group with high vit. E in the sow's diet ( $P < 0.05$ ). The highest value (52%,  $n=3$ ) was measured in pigs from sows fed sunflower oil and low vit. E. At weeks 4 and 7 the lymphocytes in all samples (12 samples per treatment) could be detected. Results showed no difference ( $P > 0.05$ ) between treatment groups. The least squares means of B-lymphocytes at 1 week of age in the low vit. E group was 9.3% ( $n=4$ ), in the medium vit. E group was 11.9% ( $n=13$ ), and in the high vit. E group was 8.4% ( $n=16$ ).

Percentages of B-lymphocytes at 4, 5 and 7 weeks of age are given in Table 6.

**Table 6. Effect of different vitamin E levels in sow's diet on percentage of B-lymphocyte<sup>a</sup> in pig blood**

Age, week	Vitamin E in sow's diet, mg/kg feed			RMSE <sup>b</sup>
	13	48	136	
% B-lymphocyte				
4	28.8	32.4	32.2	8.7
5	21.7	23.2	21.7	7.9
7	23.2	27.6	27.2	8.8

<sup>a</sup> Least squares means.

<sup>b</sup> Root mean square error.

Data in this table show that the B-lymphocyte percentage (least squares means of 24 samples per vit. E group) was only slightly ( $P > 0.05$ ) increased by a higher vit. E level in the sow's diet at 4 and 7

weeks of age. Fat source had no effect on percentage of B-lymphocytes.

**Lysozyme Activity.** Lysozyme concentrations in the blood of pigs from sows fed medium levels of vit. E at 1 week of age showed an increase ( $P < 0.05$ ) of 122% after a 50-min incubation time (Table 7).

**Table 7. Effect of different vitamin E levels in sow's diet on lysozyme concentration in pig blood<sup>a</sup>**

Age, week	Incubation time, min	Vitamin E in sow's diet, mg/kg feed			RMSE <sup>b</sup>
		13	48	136	
Lysozyme concentration					
1	0	1.85	1.99	1.82	0.51
	50	2.37 <sup>c</sup>	2.88 <sup>d</sup>	2.37 <sup>c</sup>	0.55
4	0	3.19	3.04	3.37	0.76
	50	3.57	3.46	3.38	0.72
7	0	4.24	4.59	4.36	0.64
	50	4.57	4.94	4.70	0.57

<sup>a</sup> All concentrations of lysozyme are expressed as micrograms per milliliter.

<sup>b</sup> Root mean square error.

<sup>c,d</sup> Different superscripts in the same row indicate significant differences among treatments ( $P < 0.05$ ).

The concentration of lysozyme in pigs from sows fed high vit. E was the same as than in pigs from sows fed low vit. E. At weaning and at the end of rearing, lysozyme concentration was not affected by treatment.

**Single Radial Immunodiffusion.** Immunoglobulins A and M were below the detection level of the single radial immunodiffusion technique. Data in Table 8 show that IgG level at 1 week of age was dramatically increased in all groups compared with data at birth, and that it decreased at weaning. Just after birth, when animal fat was included in the sow diet IgG levels in pig blood showed a tendency to be increased with high vit. E ( $P > 0.05$ ). At 1 week of age the highest value ( $P > 0.05$ ) was measured in the blood of offspring from sows fed animal fat and the medium level of vit. E. At weaning, the combination of high vit. E and animal fat in the sow's diet resulted in somewhat higher values of IgG in the pig's blood. At the end of rearing no treatment effect was observed.

**Enzyme-Linked Immunosorbent Assay.** The antibody production of pigs against tetanus toxoid was not affected by vit. E levels and fat sources in sow's diet. The log<sub>2</sub> titers ranged between treatment groups: at day of immunization 2.0 to 2.4; 3 weeks after immunization, 7.4 to 9.2.

**Table 8.** Effect of vitamin E and fat source in the sow's diet on IgG concentration<sup>a</sup> in pig serum

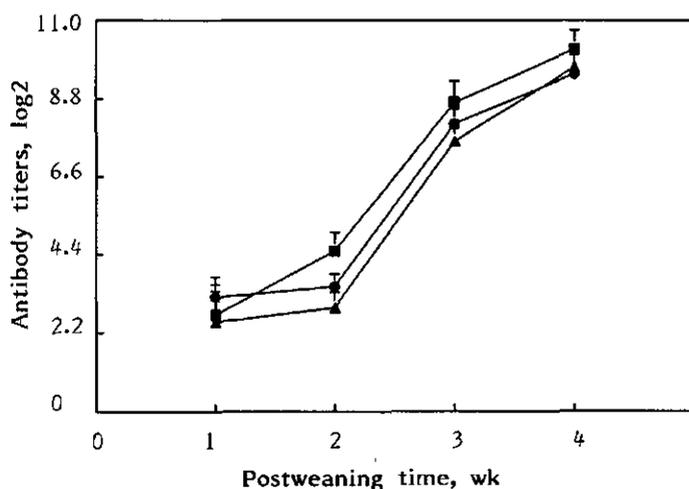
Age, week	Treatment (Code) <sup>b</sup>						RMSE <sup>c</sup>
	1(LV)	2(MV)	3(HV)	4(LA)	5(MA)	6(HA)	
0 <sup>d</sup>	0.28	0.23	0.23	0.25	0.31	0.45	0.36
1	1.97	2.06	2.60	2.02	2.90	2.38	0.96
4	1.15	1.00	1.08	1.07	1.26	1.33	0.38

<sup>a</sup> Relative values by single radial immunodiffusion.

<sup>b</sup> Treatments and codes are defined in Table 1.

<sup>c</sup> Root mean square error.

<sup>d</sup> Just after birth, before colostrum intake.



**Figure 1.** Mean antibody titers for ovalbumin (injected on week 1 after weaning) in pig blood. Three groups differed in vitamin E levels in sows' diets (13 mg/kg, ▲ ; 48 mg/kg, ● ; 136 mg/kg, ■). Mean + s.e.

Immunization with ovalbumin, however, resulted in an increased titer ( $P < 0.05$ ), 1 week after immunization in pigs originating from sows fed high vit. E compared with low vit. E group (Figure 1). The titers of pigs from sows fed animal fat were higher than those of pigs from sows fed vegetable fat ( $P < 0.05$ ). In Figure 1 it also can be seen that the antibody titers in pigs from sows fed high vit. E were higher in the whole measuring period than the titers of pigs from sows fed medium and low levels of vit. E.

## Discussion

### Alpha Tocopherol Concentrations

**Colostrum and Milk Samples.** Several studies have shown that dietary vit. E increased the vit. E concentration in sow milk (Cline et al., 1974; Young et al., 1977). This effect was consistent during lactation (Loudenslager et al., 1986). This is in agreement with results of the present study. We also found an increase in the concentrations of vit. E in colostrum and milk with high vit. E in the diets. This increase was more evident in the groups fed animal fat than in the groups fed sunflower oil. Similar trends were obtained by Malm et al. (1976). They found that the concentration of vit. E in colostrum and milk was 6 to 35 times higher in sows fed supplemental dietary vit. E than in sows without supplementation. Dietary animal fat tended to yield higher concentrations of vit. E in milk fat than corn oil ( $P > 0.05$ ).

**Blood Samples From Piglets.** The present study showed that, at birth, there was a tendency for increased levels of vit. E in serum of pigs from sows fed a high level of vit. E, especially when the diet also included animal fat. Malm et al. (1976) also showed an increase with a combination of high vit. E and lard in the sow's diet ( $P < 0.05$ ), but not with corn oil. In the current study vit. E concentration in the serum of pigs from sows fed animal fat and low levels of vit. E was the lowest. However, it should be noted that after farrowing in this group the serum vit. E concentration in sows was also the lowest (Babinszky et al., 1991). This may suggest that the placental transfer of vit. E in this group was somewhat lower than in other groups.

The present study showed in both fat groups a clear increase ( $P < 0.05$ ) in serum vit. E levels of pigs at 1 week of age with high dietary vit. E in the sow's diet. At weaning, pigs from sows fed sunflower oil had a slightly increased vit. E level in the serum ( $P > 0.05$ ). According to Ullrey (1981), there is a relatively high correlation between serum vit. E and the amount of vit. E in the body of the animal. In our investigation, at the end of lactation the increase in serum vit. E in the pigs from sows fed high levels of vit. E was less than at 1 week of age. This indicates that the vit. E in serum of the pigs was influenced by the high level of vit. E in the sow's diet to a much smaller degree than at week 1 of age. This vit. E level was, however, still associated with a high vit. E concentration in milk at time

of weaning. This clear vit. E effect in milk was not reflected in the level of vit. E in serum of pigs. We concluded that serum vit. E concentration may not reflect the vit. E status of pigs.

During the rearing period the effect almost disappeared. This is in accordance with data of Loudenslager et al. (1986). They reported an increased serum vit. E level in pigs at 2 d of age from sows fed vit. E- and selenium-supplemented diets during pregnancy. In their study, the effect disappeared at 21 d of age. Both of these studies showed that enhanced vit. E levels in the sow diet can influence vit. E levels in serum of pigs.

**Immunological Criteria in Pigs.** Yasunaga et al. (1982) injected mice with vit. E and reported an increased lymphocyte mitogen response. Bendich et al. (1986) found a positive correlation between serum vit. E levels and lymphocyte mitogen response stimulation in rat. This suggests that in rats an effect of dietary vit. E on the lymphocyte mitogen response was found if the serum vit. E was increased. In the present study no such increase of serum vit. E level in pigs at weaning or after weaning was found. This may be the reason why no effect of treatment on T-lymphocyte mitogen responses were found.

The present study showed an increased lysozyme level in blood of 1-week-old piglets from sows fed medium levels of vit. E. With the high vit. E level this concentration was decreased. A similar trend was observed by Plyashchenko and Grigorev (1985). They reported an increased humoral immune response in blood of suckling piglets when vit. E was supplemented to sow diets containing 10 mg of vit. E/kg of diet. Providing an additional 50 and 70 mg of vit. E daily per sow enhanced lysozymal activity, whereas daily addition of 100 mg/ sow had an adverse effect.

At birth the IgG levels in serum of pigs from sows fed animal fat in the present study were slightly increased ( $P > 0.05$ ). The present data showed an enhanced level of IgG at 1 week of age with medium and high dietary vit. E levels ( $P > 0.05$ ). Jackson et al. (1978) showed improved antibody titers in chicks when immunized hens were fed higher levels of vit. E. Barber et al. (1977) found an increase in total IgG level in vaccinated pigs given an i.m. injection of vit. E. Hayek et al. (1989) reported that a single i.m. injection of vit. E and(or) selenium on d 100 of pregnancy increased IgG concentrations in pig blood on d 14 of lactation. They concluded that prepartum injection of sows with vit. E and selenium can influence immunoglobulin transfer to their pigs. The results of these studies show that vit. E can influence the IgG levels in animals.

In our investigation, because of an isolation problem T- and B-lymphocytes in pig blood at 1 week of age could be measured in only a few samples. At weeks 4 and 7 the percentage of T-lymphocytes was not different ( $P > 0.05$ ) between treatments. The B-lymphocyte percentage was only slightly ( $P > 0.05$ ) increased by vit. E level in the sow's diet. Whether high doses of vit. E given to the sows can

influence the IgG level and the percentage of T- and B-lymphocytes in pigs during suckling and rearing must be elucidated in further experiments.

In our study, immunization with ovalbumin showed an increased immune response ( $P < 0.05$ ) 1 week after immunization in the pigs from sows fed high vit. E compared with pigs from sows fed low vit. E. This is a carryover effect of vit. E during lactation. Peplowski et al. (1981) showed a positive effect from vit. E in the rearing diet in weanling pigs on humoral immune responses during several weeks after immunization. Both these studies show that vit. E may have an effect on the immune response of pigs. In our study this response may be a carryover effect from the sow's diet, but the direct effect from the pig's own diet may be longer.

**In conclusion**, our study gives evidence that vit. E given in the sow diet can influence vit. E concentration in serum of pigs during the first part of lactation. The results indicated that phagocytic measures of pigs at 1 week of age may be influenced by vit. E in the sow's diet. Results also suggested that the immune response of pigs after weaning was increased by a carryover effect from the sow's diet with high vit.E levels. Fat sources in combination with different levels of vit. E in the sow's diet had no consistent effect on immunological measures tested in pigs.

## **Implications**

Survival of pigs is a very important economic issue in pig production. The present study on vitamin E shows that there may be reason to adjust vitamin E level in sows' diets to enhance vitamin E status of young pigs. The results of this study also indicated that extra vitamin E given to sows can influence some immunological measures. The health status of pigs during suckling also may be affected. After weaning, the immune response of pigs can increase as a consequence of a carryover effect from a high level of vitamin E in the sow's diet during suckling. The fat sources in the sow's diet had no consistent effect on the immunological measures tested.

## References

- Babinszky, L., D. J. Langhout, M. W. A. Verstegen, L. A. den Hartog, P. Joling and M. Nieuwland. 1991. Effect of alpha-tocopherol and dietary fat sources on some blood and immunological variables in lactating sows. *Anim. Prod.* **52**: 367-375.
- Barber, T. L., C. F. Nockels and M. M. Jochim. 1977. Vitamin E enhancement of Venezuelan equine encephalomyelitis antibody response in Guinea pigs. *Am. J. Vet. Res.* **38**: 731-734.
- Bendich, A., E. Gabriel and L. J. Machlin. 1986. Dietary vitamin E requirement for optimum immune responses in the rat. *J. Nutr.* **116**: 675-681.
- Cline, J. H., D. C. Mahan, and A. L. Moxon. 1974. Progeny effects of supplemental vitamin E in sow diets. *J. Anim. Sci.* **39**: 974. (Abstract).
- CVB. 1988. Dutch Feeding Tables. [in Dutch]. Centraal Veevoederbureau, The Netherlands.
- Hammerberg, C. and G. G. Schurig. 1986. Characterization of monoclonal antibodies directed against swine leukocytes. *Vet. Immunol. Immunopathol.* **11**: 107-121.
- Hayek, M. G., G. E. Mitchell, Jr., R. J. Harmon, T. S. Stahly, G. L. Cromwell, R. E. Tucker and K. B. Barker. 1989. Porcine immunoglobulin transfer after prepartum treatment with selenium or vitamin E. *J. Anim. Sci.* **67**: 1299-1306.
- ISO. 1979. Animal Feeding stuffs: Determination of nitrogen content and calculation of crude protein content. ISO 5983. International Organization for Standardization.
- ISO. 1983. Animal Feeding Stuffs: Determination of moisture content. ISO 6496. International Organization for Standardization.
- ISO. 1985. Animal Feeding Stuffs: Determination of fat by extraction. ISO 6492. International Organization for Standardization.
- Jackson, D. W., G. R. J. Law and C. F. Nockels. 1978. Maternal vitamin E alters passively acquired immunity of chicks. *Poult. Sci.* **57**: 70-73.
- Joling, P., L. M. B. Vaessen and J. Rozing. 1983. A two-gene control and responder mechanism regulating PHA responsiveness in rats. *Transplant. Proc.* **15**: 1616-1619.
- Lie, Ø. 1980. Genetic variation in the serum lysozyme activity in cattle. *Acta Vet. Scand.* **21**: 448-450.
- Loudenslager, M. J., P. K. Ku, P. A. Whetter, D. E. Ullrey, C. K. Whitehair, H. D. Stowe and E. R. Miller. 1986. Importance of diet of dam and colostrum to the biological antioxidant status and parenteral iron tolerance of the pig. *J. Anim. Sci.* **63**: 1905-1914.
- Malm, A., W. G. Pond, E. F. Walker, Jr., M. Homan, A. Aydin, and D. Kirtland. 1976. Effect of polyunsaturated fatty acids and vitamin E level of the sow gestation diet on reproductive performance and on level of alpha-tocopherol in colostrum, milk and dam and progeny blood serum. *J. Anim. Sci.* **42**: 393-399.
- Mancini, G., A. O. Carbonara and J. F. Heremans. 1965. Immunochemical quantitation of antigens by single radial immunodiffusion. *Immunochemistry* **2**: 235-254.
- Manz, U. and K. Philipp. 1981. A method for the routine determination of tocopherols in animal feed and human foodstuffs with the aid of high performance liquid chromatography. *Int. J. Vitam. Nutr. Res.* **51**: 342-348.
- McMurray, C. H. and D. A. Rice. 1982. Vitamin E and selenium deficiency diseases. *Ir. Vet. J.* **36**: 57-67.
- Miller, R. G. 1986. In: D.M.Weir, C.Blackwell, L.A.Herzenberg and L.A. Herzenberg (Ed.) Handbook of Experimental Immunology p. 54.1. Blackwell Scientific Publications, Oxford. UK.
- NEN. 1988. Cereals, pulps and animal feeding stuffs. Determination of crude fiber content by abbreviated method. [in Dutch]. Nederlands Normalisatie-Institut, Publ. no. 5417.
- Nockels, C. F. 1986. Nutrient modulation of the immune system. In: W.Haresign and D.J.A. Cole (Ed.) Recent Advances in Animal Nutrition. p. 177. Butterworths, London.
- Peplowski, M. A., D. C. Mahan, F. A. Murray, A. L. Moxon, A. H. Cantor and K. E. Ekstrom. 1981. Effect of dietary and injectable vitamin E and selenium in weanling swine antigenically challenged with sheep red blood cells. *J. Anim. Sci.* **51**: 344-351.

- Pharazyn, A., L. A. den Hartog and F. X. Aherne. 1990. Vitamin E and its role in the nutrition of the gilt and sow: a review. *Livest. Prod. Sci.* 24: 1-13.
- Plyashchenko, S. and G. K. Grigorev. 1985. Dependence of natural immunity in suckled piglets on vitamin E content of their mothers' diet [in Russian]. *Svinovodstvo (Moscow)* 1: 18.
- Rozing, J., N. H. C. Brons and R. Benner. 1977. B lymphocyte differentiation in lethally irradiated and reconstituted mice. II. Recovery of humoral immune responsiveness. *Cell. Immunol.* 29: 37-53.
- SAS. 1985. SAS User's Guide: Statistics. SAS Inst., Inc., Cary, NC.
- Tengerdy, R. P., R. H. Heinzerling, G. L. Brown and M. M. Mathias. 1973. Enhancement of the humoral immune response by vitamin E. *Int. Arch. Allergy Appl. Immunol.* 44: 221-232.
- Tengerdy, R. P., R. H. Heinzerling and C. F. Nockels. 1972. Effect of vitamin E on the immune response of hypoxic and normal chickens. *Infect. Immun.* 5: 987-989.
- Ullrey, D. E. 1981. Vitamin E for swine. *J. Anim. Sci.* 53: 1039-1056.
- Van Zaane, D. and M. M. Hulst. 1987. Monoclonal antibodies against porcine immunoglobulin isotypes. *Vet. Immunol. Immunopathol.* 16: 23-36.
- Vuilleumier, J. P., H. E. Keller, D. Gysel and F. Hunziker. 1983. Clinical chemical methods for the routine assessment of the vitamin status in human populations. Part I: The fat-soluble vitamins A and E, and  $\beta$ -carotene. *Int. J. Vitam. Nutr. Res.* 53: 265-272.
- Whitehair, C. K. and E. R. Miller. 1985. Vitamin E and selenium in swine production. In: *Selenium Responsive Diseases in Food Animals*. Western States Vet. Conference Symposium, Las Vegas, Nevada.
- Yasunaga, T., H. Kato, K. Ohgaki, T. Inamoto and Y. Hikasa. 1982. Effect of vitamin E as an immunopotential agent for mice at optimal dosage and its toxicity at high dosage. *J. Nutr.* 112: 1075-1084.
- Young, L. G., R. B. Miller, D. E. Edmeades, A. Lun, G. C. Smith, and G. J. King. 1977. Selenium and vitamin E supplementation of high moisture corn diets for swine reproduction. *J. Anim. Sci.* 45: 1051-1060.

## **GENERAL DISCUSSION**

## I. Introduction

One of the most important factors for the improvement of production efficiency in swine operations is to improve sow productivity (Shurson et al., 1986). This can be accomplished by increasing milk production and optimizing lactation weight loss (improving energy balance) of sows. The health status of sows and piglets may also play an important role in profitable swine production. Many factors can influence the aforementioned traits including nutritional factors.

In the present thesis the effect of two nutrients (dietary fat and vitamin E) on energy metabolism and lactation performance of primiparous sows was studied. The study of the effect of dietary vitamin E and type of dietary fat on the immune system of lactating sows and piglets was also an aim in the present investigation. In order to answer the question whether the aforementioned traits can be improved by these two nutrients three series of experiments were performed.

Chapter 1, 2 and 3 reported the effect of different levels of dietary fat and vitamin E on the energy metabolism and lactation performance of sows. The effect of dietary vitamin E and different types of dietary fat on the lactation performance and on the immune status of sows and their piglets was shown in Chapter 4, 5 and 6.

## II. Energy metabolism of lactating sows

Data on energy metabolism of sows were given in Chapter 1 and 2. In experiment 1, the energy output via milk, the heat production, and the energy balance of sows, were not affected by the moderate fat level in the lactation diet. In experiment 2, in the high fat group, the milk energy production was higher ( $P < 0.05$ ) as a consequence of the higher energy content of the milk. The heat production of sows fed a high level of dietary fat was remarkably reduced ( $P < 0.05$ ) compared to the low-fat group. The higher faeces and milk energy output of sows fed a high level of dietary fat resulted in significantly greater losses of body energy ( $P < 0.05$ ) at controlled ME intake. This more negative energy balance of sows was reflected in significantly larger body fat loss between days 18 and 25 of lactation (Chapter 1, Table 7).

The nitrogen balance of sows in both experiments was not affected by the dietary fat level.

The composition of various components which comprise digestible energy intake of sows was also determined in order to explain the results obtained from both experiment 1 and experiment 2. The calculations in this discussion have been based on the mean measurements per treatment during the balance period (between days 18 and 25 of lactation). Normally metabolizable energy is used for production and maintenance. We also calculated the contribution to total DE of various dietary components, in order to derive the contribution of fat to the energy balance. Moreover, only urinary

energy difference is related to protein. Therefore, the difference between DE and ME was only urinary energy. Gas production as  $\text{CH}_4$  and  $\text{H}_2$  was neglected because of low amounts of fibre in the diet.

Data in Table 1 show in exp.1 that in the low-fat group (St) 8.8% and in the moderate-fat group (A) 15.4% of the total DE intake of sows were derived from dietary fat. In exp.2, however, the contrast between low and high-fat group was much greater. In the low-fat group (St) 7.4 in the high-fat group (A) 24.7% of total DE was received from dietary fat. In exp.1 the very small difference in DE intake from dietary fat undoubtedly was too small to show a fat effect on the energy metabolism of sows.

**Table 1. Source of digestible energy intake of sows<sup>a</sup>**

Item	Experiment 1				Experiment 2			
	St <sup>b</sup>		A <sup>c</sup>		St <sup>b</sup>		A <sup>c</sup>	
	MJ/d	%	MJ/d	%	MJ/d	%	MJ/d	%
Total DE-intake of sow	75.15	100.0	75.34	100.0	66.17	100.0	63.53	100.0
DE intake from dietary								
protein	17.41	23.2	17.00	22.6	16.53	25.0	16.60	26.1
starch	35.26	46.9	24.92	33.0	32.11	48.5	18.20	28.6
fat	6.63	8.8	11.61	15.4	4.93	7.4	15.72	24.7
fiber	2.32	3.1	2.76	3.7	1.91	2.9	1.89	3.0
non starch NFE <sup>d</sup>	13.53	18.0	19.05	25.3	10.69	16.2	11.12	17.6

<sup>a</sup> Calculation based on the measurements during balance period (between days 18 and 25 of lactation).

<sup>b</sup> Starch (low fat) group.

<sup>c</sup> Animal fat group (in exp.1: only moderate-fat level; in exp. 2: only high-fat level).

<sup>d</sup> Calculated as  $\text{DE} - (\text{DE}_{\text{protein}} + \text{DE}_{\text{starch}} + \text{DE}_{\text{fat}} + \text{DE}_{\text{crude fiber}})$ .

Data in the literature show that the energy balance and heat production of mature, non-pregnant sows fed at approximately maintenance level (Müller and Kirchgessner, 1980; Kirchgessner and Müller, 1984) or in rats at a low ME intake (Prabucki and Schürch, 1977) were not affected by dietary fat level. This explains why in animals fed at maintenance, fat energy may be utilized slightly less efficiently than carbohydrates (Chudy and Schiemann, 1969).

If the daily ME intake of animals is higher, the heat production of growing pigs tends to decrease at a higher fat intake (Hillcoat and Annison, 1974). In our investigation, the daily ME intake was higher than in the experiments described in the literature. We found a pronounced decrease in heat production (HP) of sows fed high level of dietary fat compared with animals fed the low-fat

(carbohydrate-rich) diet. According to van Es and Boekholt (1987) this lower HP may be caused by a higher efficiency of the fat energy in the milk from dietary fat energy (95%) than from carbohydrate to milk fat energy (80%).

This lower heat production of sows may be beneficial especially at high ambient temperatures. In such conditions (e.g. in summer period in the farrowing barn) it can be more difficult to dissipate the heat increment from feed than in cool conditions (Schoenherr et al., 1989). This may result in more heat stress in carbohydrate diets compared to fat diets and may result in less feed intake (NRC, 1981).

On the basis of results for energy metabolism of sows reported in Chapter 1 the daily milk related ME intake and heat production can be calculated (Table 2).

**Table 2. Milk related metabolizable energy intake ( $ME_{milk}$ ) and heat production ( $HP_{milk}$ ) of sows measured between days 18 and 25 of lactation**

Item	Experiment 1		Experiment 2	
	St <sup>a</sup>	A <sup>a</sup>	St	A
Daily $ME_{milk}$ intake, kJ/kg <sup>0.75</sup> <sup>b</sup>	1520	1542	1454	1575
Daily $HP_{milk}$ , kJ/kg <sup>0.75</sup> <sup>c</sup>	377	357	363	287

<sup>a</sup> Codes are defined in Table 1.

<sup>b</sup>  $ME_{milk} = (ME_{feed} + ME_{body}) - ME_{maintenance}$ .

Daily maintenance requirement of sows assumed: 420 kJ ME /kg<sup>0.75</sup>.

<sup>c</sup>  $HP_{milk} = HP - ME_{maintenance}$ .  $HP_{milk}$  is corrected per experiment towards similar ME intake by assuming an efficiency of body reserve into milk of 0.8.

The total ME used for milk production and maintenance was calculated as follows:

$$ME_t = ME_{feed} - (EB/0.8), \text{ because } EB < 0$$

where:  $ME_t$  = daily total ME used for milk production and maintenance ( $ME_{feed} + ME_{body}$ ), kJ/kg<sup>0.75</sup>;  $ME_{feed}$  = daily ME intake of sows from feed (kJ/kg<sup>0.75</sup>);  $EB$  = daily energy balance of sow (kJ/kg<sup>0.75</sup>). The factor of 0.8 reflects the assumption that about 0.8 MJ of energy from body is as effective in supporting milk production as is 1 MJ of dietary ME (Verstegen et al., 1985).

The  $ME_t - ME_m$  ( $ME_m$  = daily ME maintenance = 420 kJ/kg<sup>0.75</sup>) gives the amount of ME used for milk energy production ( $ME_{milk}$ ). In exp. 2 in the high-fat group animals received 8% more energy than in the low-fat group. This difference at the nearly similar ME intake can be explained by the

more negative energy balance of sows in the high-fat group. The more negative EB of sows suggest that animals at controlled ME intake used more energy from body (fat) tissues than in the low-fat group. The daily  $HP_{milk}$  of sows was calculated from daily HP measured during the balance period ( $\text{kJ/kg}^{0.75}$ ) subtracting the daily maintenance requirement of sows ( $420 \text{ kJ ME /kg}^{0.75}$ ). Results in Table 2 show that at similar ME intake in exp. 1 the moderate-fat group sows produced about 5% less heat than in the low-fat group. In exp. 2 sows fed the high-fat diet produced 21% less heat (HP for milk production) than those fed the low-fat diet.

The heat associated with milk energy synthesis ( $HP_{milk}$ ) provides an opportunity for the calculation of the efficiency of dietary fat for milk fat production. This calculation was done only in exp.2 since in this experiment the contrast in dietary fat intake of sows was larger than in exp.1. This calculation was done as follows:

$$\Delta HP_{milk,c} = \Delta \text{dig.St} * (17.5 - 14.66) + \Delta \text{dig.fat} * (39.3 - x)$$

$$\text{Eff} = x / 39.3$$

where:  $\Delta HP_{milk,c}$  = difference in milk related HP of sows (corrected towards similar ME intake by using body energy) between low (St) and high-fat (A) group (St-A; kJ/d);  $\Delta \text{dig.St}$  = difference in daily digestible starch intake between low (St) and high-fat (A) group (St-A; g/sow); 17.5 kJ/g = gross energy content of starch; 14.66 kJ/g NE content of starch (Noblet et al., 1989);  $\Delta \text{dig.fat}$  = difference in daily digestible fat intake of sows between low (St) and high-fat (A) group (St-A; g/sow); 39.3 kJ/g = gross energy content of fat;  $x$  = NE content of fat (kJ/g); Eff = efficiency of milk fat production from dietary fat.

The abovementioned formulas, give a value of 35 kJ/g NE content of fat ( $x$ ) and of 0.89 for the efficiency of dietary fat for milk fat production. This efficiency is somewhat lower than that reported by van Es and Boekholt (1987). However, it should be noted that in our calculation we assumed that NE content of starch is 14.66 kJ/g (Noblet et al., 1989). This value indicates that the efficiency of milk fat production from starch is 84% ( $14.66/17.5$ ). However, if we assume an efficiency of 0.8 for milk fat production from starch (van Es and Boekholt, 1987) the efficiency for dietary fat is even higher (94%).

The other remarkable result is the change in respiratory quotients (RQ) of sows (Chapter 2). It was found, that in both experiments in the fat groups the RQ was significantly lower than in carbohydrate groups (low-fat groups). A similar tendency for RQ was found in mature non-pregnant sows (Müller and Kirchgessner, 1980) and in rats (Prabucki and Schürch, 1977). The higher RQ for

sows fed the low or moderate-fat diet indicates that more milk fat is synthesized from carbohydrates (Brouwer, 1958).

In our study, the daily total milk fat production (from diet and body tissues), and the amount of milk fat potentially synthesized from dietary fat and the rest from non-fat nutrients in diet were calculated. The results are given in Table 3. Data show that the total milk fat production in exp.1 in the moderate-fat group was about 5% higher than in the low-fat group. In exp. 2 animals in the high-fat group produced 20% more milk fat than those fed the low-fat diet.

Data also indicated that animals receiving the moderate or high-fat level diet could produce somewhat more milk fat from the diet than the sows fed the carbohydrate-rich diets.

In experiment 2, in the high-fat group, the daily dietary digestible fat intake was higher than milk fat production from diet (400 and 349 g/d respectively). Therefore, animals had 51 g/day of dietary fat available for purposes other than milk. Data from exp.2 show that sows fed a high dietary fat level had no need to use the non-fat nutrients of the diet for milk fat production. These findings are in accordance with the change of RQ values.

**Table 3. Fat balance in sows. Milk fat, body fat losses, dietary fat and fat to be synthesized from non-fat nutrients in diets between days 18 and 25 of lactation (g/day/sow)**

Item	Experiment 1		Experiment 2	
	St <sup>a</sup>	A <sup>a</sup>	St	A
Daily milk fat production, g/sow				
total <sup>b</sup>	729	765	711	855
fat mobilization from body	316	317	381	506
from diet	413	448	330	349
from dietary fat	169	295	125	400
from non-fat nutrients	244	153	205	(-51) <sup>c</sup>

<sup>a</sup> Codes are defined in Table 1.

<sup>b</sup> From diet and body tissues.

<sup>c</sup> 51 g of dietary fat used for other purposes.

The dietary vitamin E content had no effect on the energy and nitrogen balances of sows. The HP and RQ were also not influenced by different levels of vitamin E in the lactation diet. It had been thought that fat uptake in the gastrointestinal tract may have been affected by dietary vitamin E level and so also the energy metabolism of sows, however, no effect of vitamin E on fat digestibility was found.

To summarize, it can be stated that sows fed high level of dietary fat during lactation have a more negative energy balance and lose more body fat at controlled ME intake than those fed the low-fat

diets. Lactating sows fed a high level of dietary fat produce less heat than sows fed a low-fat diet. The higher respiratory quotients and the calculated amount of milk fat from non-fat nutrients in the diet for sows fed low or moderate dietary fat level, indicate that those animals also needed to synthesize milk fat from other dietary sources, probably carbohydrates.

### III. Milk composition and milk production of sows

#### *Composition of milk*

The composition of colostrum and milk at different stages of lactation were presented in Chapters 3 and 4. Results at days 14 and 27 of lactation, show that only the high level of dietary fat had an effect on the composition of milk (Chapter 3, exp. 2). On both days of lactation dry matter, fat, and energy content of milk from sows fed a high level of dietary fat were significantly increased ( $P < 0.05$ ). These results are in agreement with data in the literature. In many studies, it was found that a higher dietary fat level increased the fat content of milk (Moser and Lewis, 1980; Pettigrew, 1981; Boyd et al., 1982; Coffey et al., 1982).

The effect of the type of dietary fat and the level of dietary vitamin E, on the composition of colostrum and milk was given in Chapter 4. The dietary fat and vitamin E had no effect on the composition of colostrum. At the end of lactation, the dry matter and fat content of milk were significantly higher in the sunflower oil group than in the animal fat group. We found that the dry matter and fat content of milk from sows fed the medium level of vitamin E in the diet, were significantly higher than in the high vitamin E group. Whether the milk fat and dry matter content of milk are affected by the type of dietary fat and vitamin E must be studied in further experiments. However, it should be noted that data reported by Pettigrew (1981) suggested there was a higher fat content in milk from sow fed corn oil than from sow fed animal fat. The protein content in milk was not influenced by level and type of dietary fat, nor by the level of dietary vitamin E.

The effect of different levels of dietary vitamin E and types of dietary fat on the  $\alpha$ -tocopherol content in colostrum and milk (at weaning) will be discussed later in this Chapter (Paragraph V).

**In conclusion**, our study and data from the literature, give evidence that high levels of fat in the lactation diet can increase the fat and energy content of milk. The type of dietary fat and the level of dietary vitamin E had no clear effect on the composition of the milk.

**Milk production**

The milk production of sows during lactation was not affected by dietary fat and vitamin E level (Chapter 3 and 4). Although the effect of dietary fat and vitamin E level on the milk production has been extensively studied, the results have not been consistent. This was already discussed in the General Introduction. Results from the literature show only a slight effect of fat on milk yield (Pettigrew, 1981; Coffey et al., 1982) or no effect at all (Lellis and Speer, 1983). This may be explained because many of the factors which influence the utilization of dietary fat (ME intake of sows, measuring techniques, parities, a.s.o.) were not consistent in these studies as was discussed in the General Introduction.

Our data on milk yield indicate that a high level of fat in the lactation diet had no effect on the amount of milk production of primiparous sows (Chapter 3.). On the other hand, the efficiency of milk production from ME-feed above maintenance, was significantly higher for sows fed the high level of dietary fat than for sows fed the low-fat diet (Chapter 1; exp.2). This higher energetic efficiency of milk production indicates a more efficient production of milk fat from dietary fat than from dietary starch.

Results of a study of Schoenherr et al. (1989) also supported the hypothesis that dietary energy in lactating sows may be utilized more efficiently for milk production when it is obtained from fat than when derived from starch. This concurs with our results.

Lellis and Speer (1983) also concluded from their results, that the efficiency of milk production was higher for multiparous sows fed tallow than for sows fed dextrose. The higher efficiency of milk production indicated that in sows fed higher levels of dietary fat the energy cost for milk fat production was lower than for sows fed carbohydrate-rich (low-fat level) diet.

In our investigation, the milk yield during the entire lactation was not significantly affected by the vitamin E level in the sow's diet. However, it should be noted that milk yield on the first three measuring days (first two weeks of lactation) tended to be higher in the high vitamin E group (126 mg/kg diet) than in the low vitamin E group (14 mg/kg diet) (Chapter 4.). We made a similar observation in a subsequent study using nearly the same vitamin E levels (Babinszky, L., M.W.A. Verstegen and L.A.den Hartog, unpublished data). These findings may indicate that milk production of sows in early lactation may be slightly increased by high level of dietary vitamin E. However, this needs to be checked in further trials. According to Adams and Zimmerman (1982) the vitamin E effect on milk yield is more pronounced in multiparous sows than in gilts. Maybe this is why no clear vitamin E effect was found in our trials with first parity sows. The absence of vitamin E effect on milk production may be also why no vitamin E effect on energy balance of sows was observed.

**In conclusion**, it can be stated, that a high level of dietary fat in the lactation diet can increase the dry matter, fat and energy content of milk. The type of dietary fat and the dietary vitamin E level did not clearly affect the dry matter and fat content of milk. The daily milk production was not significantly affected by dietary fat nor by the vitamin E level. However, the energetic efficiency of milk production from ME-feed is improved ( $P < 0.05$ ) when sows were fed at high levels of dietary fat.

#### **IV. Performance of sows and piglets**

In all experiments, sows lost weight and backfat during lactation (Chapter 3 and 4.). The live weights and backfat of sows was not affected by dietary fat (type and level of fat) and by dietary vitamin E level during lactation. Sows fed a high level of dietary fat had relatively large weight and body fat loss during the balance period (Chapter 1, exp.2). The large weight loss is related to the greater energy output via milk.

Live weight of piglets during lactation was not significantly affected by the dietary fat levels in the lactating sow's diet. However, during the period of measurements (between days 18 and 25 of lactation) piglets from sows fed a high level of dietary fat had higher daily gain ( $P < 0.05$ ) than piglets from sows fed low dietary fat (Chapter 3, exp.2). These results, from a wellcontrolled 7-day-period suggest that high fat level in the lactation diet, can increase the daily gain of piglets. Pettigrew (1981) similarly concluded from the literature that the mean piglet weight at weaning appears to increase if the fat concentration in the sows diet is at least 8%. In our study the beneficial effect of dietary fat on the daily gain of piglets was found in the second half of lactation.

The present studies also indicate that vitamin E level and the type of fat (sunflower oil and animal fat) in the pregnancy and lactation diet had no significant effect on the litter size, piglets' birth and weaning weight. These results confirm the literature data which suggest that the piglets' performance was not clearly affected by different levels of vitamin E (Malm et al., 1976; Nielsen., 1979). On the other hand, in other investigations, the extra vitamin E had a positive effect on piglets' performance although the response to the treatment was more pronounced in multiparous sows than in gilts (Adams and Zimmerman, 1982, Chavez and Patton, 1986). Whether at conditions with higher vitamin E demand a beneficial effect can be expected may depend on vitamin E storage within the body.

Generally, from our results it can be concluded that a high fat level in the sow's lactation diet may increase the daily gain of piglets in the second half of lactation. The type of dietary fat and the vitamin E level in the sow's diet had no clear effect on the performance of the sows and piglets.

## V. Alpha-tocopherol concentration in serum, colostrum and milk

Data on  $\alpha$ -tocopherol concentration in serum from sows and piglets, and in colostrum, and milk (reported earlier in Chapter 5 and 6) are summarized in Table 4. The relative value of measurements are given in Table 5.

### Serum from sows

Results showed that a high vitamin E level in the gestation and lactation diet which included either sunflower oil or animal fat, increased the serum  $\alpha$ -tocopherol concentration in the sows ( $P < 0.05$ ) just after farrowing and at weaning (Chapter 5). This increase of  $\alpha$ -tocopherol was expected because several papers also reported that  $\alpha$ -tocopherol concentration in the blood of sows could be enhanced by extra dietary vitamin E (Malm et al., 1976; Loudenslager et al., 1986).

**Table 4. Vitamin E intake of sows during lactation and alpha-tocopherol concentration in serum of sows and piglets and in colostrum and milk (data derived from Chapters 5 and 6)**

Item	Treatment <sup>a</sup>					
	LV	MV	HV	LA	MA	HA
Vit. E intake of sows mg/day	55	207	581	64	235	630
Alpha tocopherol in colostrum <sup>b</sup>						
$\mu\text{g/g}$ fat	334	393	449	182	429	593
milk						
$\mu\text{g/g}$ fat	46	48	66	14	30	65
sow's serum, mg/l						
post partum <sup>b</sup>	1.50	1.63	2.35	0.72	1.30	2.25
at weaning	2.47	2.03	3.60	0.97	1.97	3.43
piglets serum, mg/l						
at birth <sup>b</sup>	0.19	0.15	0.21	0.08	0.13	0.17
1 week after birth	4.74	4.56	6.36	3.33	5.27	6.43
at weaning	2.48	2.69	3.31	1.60	2.53	1.93

<sup>a</sup> Dietary vitamin E level: L (low), M (medium), H (high); dietary fat: V (vegetable fat: sunflower oil), A (animal fat).

<sup>b</sup> During pregnancy all sows in all treatment groups received 2.4 kg feed /day.

However, it should be noted also, that sows fed low dietary vitamin E level combined with animal fat had the lowest level of serum  $\alpha$ -tocopherol after farrowing and at weaning, compared with other treatment groups.

The present trial does not explain the low serum  $\alpha$ -tocopherol concentration in animals fed a low vitamin E level combined with animal fat. The animals may perhaps store more  $\alpha$ -tocopherol in the body than in the other groups. It could also be that  $\alpha$ -tocopherol uptake from the diet is reduced compared to vegetable fat. However, this hypothesis has to be confirmed in further experiments.

#### *Serum from piglets*

The  $\alpha$ -tocopherol concentration in piglets serum just after birth (before colostrum intake) was low and was not significantly affected by the dietary vitamin E intake of sows. Pharazyn et al. (1990) concluded from the literature, that the low plasma and tissue levels of  $\alpha$ -tocopherol in the newborn pigs indicated a low rate of vitamin E transfer across the placenta. Thus it is unlikely to be influenced by dietary supplementation of vitamin E in the sow's diet. Our study, however, showed that in both fat groups, a small increase in serum  $\alpha$ -tocopherol concentration was found in piglets from sows fed high dietary vitamin E during gestation.

**Table 5. Relative values of the measurements<sup>a</sup> presented in Table 4**

Item	Treatment <sup>b</sup>					
	LV	MV	HV	LA	MA	HA
Vit. E intake of sows	100	376	1056	100	367	984
Alpha tocopherol in:						
colostrum	100	118	134	100	236	326
milk	100	104	143	100	214	464
sow's serum						
after farrowing	100	109	157	100	181	313
at weaning	100	82	146	100	203	354
piglets serum						
at birth	100	79	111	100	163	213
1 week after birth	100	96	134	100	158	193
at weaning	100	108	133	100	158	121

<sup>a</sup> In both fat groups low vitamin E (L) is 100%.

<sup>b</sup> Treatments are defined in Table 4.

The  $\alpha$ -tocopherol levels in blood serum at 1 week of age were increased in both fat groups by higher levels of vitamin E in the sows diet ( $P < 0.05$ ). This indicated that the  $\alpha$ -tocopherol concentration in piglets' serum can be increased via colostrum and milk intake. But at the end of the lactation (4 weeks of lactation) the higher  $\alpha$ -tocopherol concentration in the milk was not reflected in the level of  $\alpha$ -tocopherol in the serum of the piglets. This suggests that serum  $\alpha$ -tocopherol concentration may not completely reflect the  $\alpha$ -tocopherol status of piglets.

#### *Colostrum and milk*

Data on  $\alpha$ -tocopherol concentration in colostrum and milk are reported in Chapters 4, 5 and 6 and are summarized in Table 4. They demonstrate that a high level of dietary  $\alpha$ -tocopherol intake with animal fat during gestation had a greater effect on the concentration of colostrum  $\alpha$ -tocopherol than with sunflower oil. At the end of lactation, the highest values in high vitamin E groups were found and no difference was observed between HV (high vitamin E plus sunflower oil) and HA (high vitamin E plus animal fat) groups. At the end of lactation the increase of  $\alpha$ -tocopherol in milk was more pronounced in the animal fat group than in the sunflower oil group. From the present study it is not clear why this effect of animal fat was found. Malm et al. (1976) also found that animal fat from lard tended to promote a higher concentration of  $\alpha$ -tocopherol in milk fat than did corn oil. The dietary vitamin E effect was expected because several studies showed that the  $\alpha$ -tocopherol content of sow's milk was increased after extra dietary vitamin E (Nielsen et al., 1973; Cline et al., 1974; Malm et al., 1976; Young et al., 1977). This shows that piglets from sows fed high levels of dietary vitamin E during lactation, have ingested more  $\alpha$ -tocopherol via milk than piglets from sows fed low levels of dietary vitamin E.

**In summary:** it can be concluded that a high level of vitamin E in the sow's diet which includes either sunflower oil or animal fat, significantly increased the serum  $\alpha$ -tocopherol concentration in sows just after farrowing and also at weaning. In colostrum, the combination of high dietary vitamin E with animal fat gave the highest  $\alpha$ -tocopherol concentration. At weaning  $\alpha$ -tocopherol in milk fat was highest in both fat groups with high dietary vitamin E. The  $\alpha$ -tocopherol concentration in piglet serum at only one week of age was increased significantly by the high level of dietary vitamin E in the sow's diet. Data from the present studies (Table 5) also indicate that the higher dietary vitamin E intake of sows may have a greater effect on  $\alpha$ -tocopherol concentration in sow's serum, colostrum and milk (direct effect via feed) than on  $\alpha$ -tocopherol concentration in piglets serum (indirect effect via sow milk). Data also suggest that the serum  $\alpha$ -tocopherol concentration may not completely reflect

the vitamin E status of piglets. Some other parameters like total body vitamin E may be a better indicator than serum vitamin E.

## VI. Blood and immunological variables of sows and piglets

### *General remarks*

During the course of our studies of vitamin E, we determined the effects of vitamin E on some blood cell parameters such as total leucocyte counts, lymphocyte differentiation and immunoglobulin levels. On the other hand, it seems of importance to test active immune parameters such as lymphocyte stimulation, antibody production and lysozyme activity. These immune characteristics may be of importance for the health status of sows and piglets.

### *Sows*

Percentages of T-lymphocytes and a lymphocyte stimulation test showed no vitamin E or fat effect post partum or at weaning (Chapter 5). During lactation only a small increase in percentages of T-lymphocytes was observed in all treatment groups. Results indicate that cell-mediated immunity of sows as tested, were not significantly affected by vitamin E supplementation or by fat addition to the diet.

The percentage of B-lymphocytes after farrowing was not affected by dietary vitamin E. The sunflower oil group, however, showed a higher value for B-lymphocytes than the animal fat group ( $P < 0.05$ ). At the end of lactation, some increase in B-lymphocytes was found with increasing dietary vitamin E intake. In the sunflower oil group, this value was higher ( $P < 0.05$ ) than in the animal fat group. Data on B-lymphocytes may suggest that the humoral immune status of sows at weaning was only slightly affected by dietary vitamin E. However, it should be noted also that at that time this higher percentage of B-lymphocytes was related to a decreased level of serum IgG. This phenomenon illustrates that the number of B-lymphocytes is a reflection of the capacity of antibody production and not of the actual serum Ig levels. A regulatory role of vitamin E on the antibody production was discussed in Chapter 5.

Several papers reported increased antibody production in animals after supplementation with vitamin E (Nockels, 1986; Pharazyn et al., 1990). However, our data suggest a discrepancy between specific antibody production and the total immunoglobulin values. This may indicate that the total immunoglobulin concentration gives only part of the information about the humoral immune response of animals. At the end of lactation the lowest values of IgG in milk were found in sows fed most vitamin E ( $P < 0.05$ ). This response is similar to that recorded for serum IgG concentrations.

### *Piglets*

The results for immunological variables in piglets were given and have been discussed in Chapter 6. The blood and immunological parameters tested, indicate that the vitamin E levels and types of fat in the sows' diet had no effect on the cell-mediated immunity of suckling and weaned piglets. Bendich et al. (1986) reported a positive correlation between serum  $\alpha$ -tocopherol levels and lymphocyte mitogen response stimulation in rats. This suggests that in rats an effect of dietary vitamin E on the lymphocyte mitogen response was found if the serum  $\alpha$ -tocopherol was increased. In our study, no such increase of serum  $\alpha$ -tocopherol in piglets at weaning or after weaning was found. This may be the reason why no treatment effect on T-lymphocyte mitogen responses were found compared to the study of Bendich et al. (1986). These results again emphasize the need to measure the vitamin E digestibility as a measure of uptake of vitamin E.

The IgG levels just after birth were very low in all treatment groups. Values for IgG in piglets serum before colostrum intake may be explained by the development of immunocompetence by pig foetuses after 70 days of gestation according to Jönsson, 1973; Metzger et al., 1978 and Watson et al., 1979. Although the IgG levels at 1 week of age were increased in all groups compared with data at birth, no significant treatment effect was found. Hayek et al. (1989) reported that a single i.m. injection of vitamin E and/or selenium on day 100 of pregnancy significantly increased IgG concentrations in the piglets blood on day 14 of lactation. Such a clear vitamin E effect was not found in our investigation. In our study, the specific antibody production against ovalbumin resulted in an increased titre ( $P < 0.05$ ) one week after immunization in weaned piglets originating from sows fed a high level of dietary vitamin E. This may suggest that there is a carryover effect on piglets postweaning from the level of vitamin E in the sow's diet during suckling. In the present study, the antibody production of pigs against tetanus toxoid was not affected by vitamin E. Peplowski et al. (1981) showed a positive effect from vitamin E in the rearing diet in weaning pigs on the humoral immune response during several weeks after immunization. Both studies indicate that vitamin E can have an effect on immune response of piglets. In our study this response may be a carryover effect from the sow's diet, though the study of Peplowski et al. (1981), suggests that a direct effect of the piglets' diet on the immune response may be longer. Both may be expressions of the same phenomenon.

On the other hand, studies with weaned piglets did not indicate an effect of dietary vitamin E on humoral and cell-mediated immune response (Kornegay, 1986; Bonnette et al., 1990 a,b). Inconsistent data in the literature, indicate that many other factors which are not related directly to the treatments such as different history of animals before experiment, different age, antigens, experimental approach, and different environment, also may influence the effect of vitamin E.

In our study, an increased lysozyme level was found in the blood of one-week-old piglets from sows fed medium levels of vitamin E. With the high vitamin E level, however, this concentration decreased. This may indicate that the medium level of vitamin E in the lactation sow's diet can increase the lysozyme activity of pigs at one week of age. A similar observation was made with suckling piglets by Plyashchenko and Grigorev (1985). Both studies suggested that a high level of vitamin E in the sow's diet depressed the lysozyme concentration in piglets' blood. The reason of decrease effect of high level of dietary vitamin E on the concentration of lysozyme from the present study is not known.

**In conclusion**, it can be stated that the cell-mediated immunity as determined by mitogen stimulation and the lysozyme activity of sows were not affected by dietary vitamin E levels or by different types of dietary fat. The humoral immune system was only slightly influenced by the combinations of vitamin E and fat used. These results suggest that the dietary vitamin E has some effect (although minor) on the immune system in adult animals.

The cell-mediated immunity as measured in suckling and weaned piglets was not affected by the level of vitamin E in the sow's diet. However, the humoral immune response was increased at one week of age after immunization for weaned piglets from sows fed the high level of vitamin E during suckling. Also, the lysozyme activity of piglets at one week of age was increased by the medium vitamin E level in the sow's diet. There was no carryover effects of vitamin E in the sow's diet on the performance of piglets. It cannot be excluded that under more stressful conditions there might have been differences and in that case a high dietary vitamin E may be beneficial. Fat sources in the sow's diet had no consistent effect on the immunological measurements of piglets.

## VII. Final conclusions

From the studies of present thesis the following conclusions can be drawn:

1. A high level of fat in the lactation diet (125 g/kg DM) decreased the daily heat production of sows compared to the low fat level (37 g fat/kg DM). This lower heat production can have a beneficial effect on energy intake of sows, especially at high ambient temperatures.
2. Daily milk-related heat production is lower for sows fed a high level of dietary fat compared to the sows fed a diet in which the dietary fat level was lower and dietary starch higher.

3. The high respiratory quotients and the calculated amount of milk fat from non-fat nutrients in the diet, indicated that sows fed low (37 or 43 g fat/kg DM) or a moderate-fat diet (75 g fat/kg DM) needed to synthesize more milk fat from other dietary sources than from fat, i.e. carbohydrates compared to high-fat diet (125 g fat/kg DM).
4. The partial efficiency of milk energy production from metabolizable energy from dietary fat was estimated to be from 89 to 94 %.
5. The efficiency of milk production from ME-feed above maintenance requirement, was improved significantly when sows were fed high level of dietary fat during lactation.
6. The moderate level of dietary fat (75 g fat/kg DM) showed no difference in the metabolic rate of lactating sows compared to the low level (43 g fat/kg DM). Also, the energy metabolism of sows was not influenced by the different levels of dietary vitamin E.
7. The milk production of sows was not improved by high level of dietary fat nor by different levels of dietary vitamin E.
8. The lactation performance of piglets was not clearly influenced by the different levels of dietary fat nor by the vitamin E in the sow's diet.
9. The high level of vitamin E in the sow's diet including either sunflower oil or animal fat significantly increased the serum  $\alpha$ -tocopherol concentration in sows just after farrowing and at weaning. The  $\alpha$ -tocopherol concentration in piglet serum at only one week of age was increased significantly by the high level of dietary vitamin E in the sow's diet.
10. The combination of high dietary vitamin E with animal fat gave the highest  $\alpha$ -tocopherol concentration in colostrum. At weaning,  $\alpha$ -tocopherol in milk fat was highest in both fat groups with high dietary vitamin E.
11. We did not demonstrate any effect of the cell-mediated immunity of lactating sows by dietary vitamin E levels. The humoral immune system of sows was only slightly affected by the combination of vitamin E and fat given.

12. The cell-mediated immunity of suckling and weaned piglets was not affected by different levels of vitamin E or types of dietary fat in the sow's diet. Assuming that an increase of antibody production (against ovalbumin) is beneficial for immune reactivity, the high level of vitamin E in the sow's diet during lactation can improve the immune status of weaned piglets one week after immunization.
  
13. The medium level of vitamin E (48 mg/kg) in the pregnancy and lactation diet can increase the lysozyme concentration in piglets at one week of age, which indicates a higher lysozyme activity.
  
14. The results of our studies show that a high level of fat in the sow's lactation diet can influence the energy metabolism of sows and the energetic efficiency of milk production. The high dietary fat level improved the milk fat output.  
The high level of dietary vitamin E in the pregnancy and lactation diet had no consistent effect on the cell-mediated and humoral immune response of lactating sows. The results of present studies suggest that there may be reason to adjust vitamin E levels in sow's diets to improve some immunological variables in piglets. The fat sources in the sow's diet had no consistent effect on the piglets immunological parameters.

## References

- Adams, C.R. and C.R. Zimmerman. 1982. Many factors affect pigs' vitamin E needs. *Feedstuffs* 24: 30-31.
- Bendich, A., E. Gabriel and L.J. Machlin. 1986. Dietary vitamin E requirement for optimum immune responses in the rat. *J. Nutr.* 116: 675-681.
- Bonnette, E.D., E.T. Kornegay, M.D. Lindemann and C. Hammerberg. 1990a. Humoral and cell-mediated immune response and performance of weaned pigs fed four supplemental vitamin E levels and housed at two nursery temperatures. *J. Anim. Sci.* 68: 1337-1345.
- Bonnette, E.D., E.T. Kornegay, M.D. Lindemann and D.R. Notter. 1990b. Influence of two supplemental vitamin E levels and weaning age on performance, humoral antibody production and serum cortisol levels of pigs. *J. Anim. Sci.* 68: 1346-1353.
- Boyd, R.D., B.D. Moser, E.R. Peo, Jr., A.J. Lewis and R.K. Johnson. 1982. Effect of tallow and choline chloride addition to the diet of sows on milk composition, milk yield and preweaning pig performance. *J. Anim. Sci.* 54: 1-7.
- Brouwer, E. 1958. On simple formulae for calculating the heat expenditure and the quantities of carbohydrate and fat metabolized in ruminants, from data on gaseous exchange and urine-N. In: G. Thorbek and H. Aersøe (Eds) 1. Symposium on Energy Metabolism. Proc. pp. 182-192. EAAP Publication No. 8. Statens Husdyrbrugsudvalg, Copenhagen, Denmark.
- Chavez, E.R. and K.L. Patton. 1986. Response to injectable selenium and vitamin E on reproductive performance of sows receiving a standard commercial diet. *Can. J. Anim. Sci.* 66: 1065-1074.
- Chudy, A. and R. Schiemann. 1969. Utilization of dietary fat for maintenance and fat deposition in model studies with rats. In: K.L. Blaxter, J. Kielanowski and G. Thorbeck (Eds) Energy Metabolism of Farm Animals. pp. 161-168. EAAP Publications. Publication No. 12. Oriel Press, England.
- Cline, J.H., D.C. Mahan and A.L. Moxon. 1974. Progeny effects of supplemental vitamin E in sow diets. *J. Anim. Sci.* 39: 974 (Abstract).
- Coffey, M.T., R.W. Seerley and J.W. Mabry. 1982. The effect of source of supplemental dietary energy on sow milk yield, milk composition and litter performance. *J. Anim. Sci.* 55: 1388-1394.
- Es, A.J.H. van and H.A. Boekholt. 1987. Energy metabolism of farm animals. In: M.W.A. Verstegen and A.M. Henken (Eds) Energy Metabolism in Farm Animals. pp.3-19. Martinus Nijhoff Publishers, Dordrecht.
- Hayek, M.G., G.E. Mitchell, Jr., R.J. Harmon, T.S. Stahly, G.L. Cromwell, R.E. Tucker and K.B. Barker. 1989. Porcine immunoglobulin transfer after parturition treatment with selenium or vitamin E. *J. Anim. Sci.* 67: 1299-1306.
- Hillcoat, J.B. and E.F. Annison. 1974. The efficiency of utilization of diets containing maize oil, tallow and tallow acid oil in the pig. In: K.H. Menke, H.J. Lantzsch and J.R. Reichl (Eds) Energy Metabolism of Farm Animals. pp. 177-180. EAAP Publications. Publication No. 14. Universität Hohenheim, Germany.
- Jönsson, A. 1973. Transfer of immunoglobulins from mother to offspring in the pig. *Acta Vet. Scand. Suppl.* 43: 1-64.
- Kirchgessner, M. and H.L. Müller. 1984. Thermogenese bei Verabreichung einer ketogenen Diät im Modellversuch an Sauen [in German]. *Int. J. Vitam. Nutr. Res.* 54: 99-106.
- Kornegay, E.T., J.B. Meldrum, G. Schurig, M.D. Lindemann and F.C. Gwazdauskas. 1986. Lack of influence of nursery temperature on the response of weanling pigs to supplemental vitamins C and E. *J. Anim. Sci.* 63: 484-491.
- Lellis, W.A. and V.C. Speer. 1983. Nutrient balance of lactating sows fed supplemental tallow. *J. Anim. Sci.* 56: 1334-1339.
- Loudenslager, M.J., P.K. Ku, P.A. Whetter, D.E. Ullrey, C.K. Whitehair, H.D. Stowe and E.R. Miller. 1986. Importance of diet of dam and colostrum to the biological antioxidant status and parenteral iron tolerance of the pig. *J. Anim. Sci.* 63: 1905-1914.

- Malm, A., W.G. Pond, E.F. Walker, Jr., M. Homan, A. Aydin and D. Kirtland. 1976. Effect of polyunsaturated fatty acids and vitamin E level of the sow gestation diet on reproductive performance and on level of alpha tocopherol in colostrum, milk and dam and progeny blood serum. *J. Anim. Sci.* 42: 393-399.
- Metzger, J.J., C. Ballet-Lapierre and M. Houdayer, 1978. Partial inhibition of the humoral immune response of pigs after early postnatal immunization. *Am. J. Vet. Res.* 39: 627-631.
- Moser, B.D. and A.J. Lewis. 1980. Adding fat to sow diets. An update. *Feedstuffs* 52: 36-62.
- Müller, H.L. and M. Kirchgessner. 1980. Energy utilization of a carbohydrate-free protein-fat diet by sows. In: L.E. Mount (Ed) *Energy Metabolism*. pp. 249-252. EAAP Publications. Publication No. 26. Butterworths, London.
- Nielsen, H.E., V. Danielsen, M.G. Simesen, G. Gissel-Nielsen, W. Hjarde, T. Leth and A. Basse. 1979. Selenium and vitamin E deficiency in Pigs. I. Influence on growth and reproduction. *Act. Vet. Scand.* 20: 276-288.
- Nielsen, H.E., N.J. Højgaard-Olsen, W. Hjarde and E. Leerbeck. 1973. Vitamin E content in colostrum and sow's milk and sow milk yield at two levels of dietary fats. *Acta Agric. Scand. Suppl.* 19: 35-38.
- Noblet, J., H. Fortune, S. Dubois and Y. Henry. 1989. Nouvelles bases d'estimation des teneurs en énergie digestible, métabolisable et nette des aliments pour le porc [in French]. pp.106. Institut National del la Recherche Agronomique (INRA), Paris.
- Nockels, C.F. 1986. Nutrient modulation of the immune system. In: W. Haresign and D.J.A. Cole (Eds) *Recent Advances in Animal Nutrition*. pp. 177-192. Butterworths. London.
- NRC. 1981. *Effect of environment on nutrient requirements of domestic animals*. pp. 152. National Academy Press, National Research Council, Washington, D.C.
- Peplowski, M. A., D. C. Mahan, F. A. Murray, A. L. Moxon, A. H. Cantor and K. E. Ekstrom. 1981. Effect of dietary and injectable vitamin E and selenium in weanling swine antigenically challenged with sheep red blood cells. *J. Anim. Sci.* 51: 344-351.
- Pettigrew, J.E., Jr. 1981. Supplemental dietary fat for peripartur sows: a review. *J. Anim. Sci.* 53: 107-117.
- Pharazyn, A., L.A. den Hartog and F.X. Aherne. 1990. Vitamin E and its role in the nutrition of the gilt and sow: a review. *Livest. Prod. Sci.* 24: 1-13.
- Plyashchenko, S. and G. K. Grigorev. 1985. Dependence of natural immunity in suckled piglets on vitamin E content of their mothers' diet [in Russian]. *Svinovodstvo (Moscow)* 1: 18.
- Prabucki, A.L. and A. Schürch. 1977. The heat production of rats fed isocaloric and protein-equivalent diets with different proportions of fat to carbohydrates. *Bibl. Nutr. Dieta (Basle)* 25: 78-82.
- Schoenherr, W.D., T.S. Stahly and G.L. Cromwell. 1989. The effects of dietary fat or fiber addition on yield and composition of milk from sows housed in a warm or hot environment. *J. Anim. Sci.* 67: 482-495.
- Shurson, G.C., M.G. Hogberg, N. DeFever, S.V. Radecki and E.R. Miller. 1986. Effects of adding fat to the sow lactation diet on lactation and rebreeding performance. *J. Anim. Sci.* 62: 672-680.
- Verstegen, M.W.A., J. Mesu, G.J.M. van Kempen and C. Geerse. 1985. Energy balances of lactating sows in relation to feeding level and stage of lactation. *J. Anim. Sci.* 60: 731-740.
- Watson, D.L., M.A. Bennell and T.D. Chaniago. 1979. Effect of circulating, maternally derived antibody on the development of a local immune response in the intestine of the neonatal pig. *Am. J. Vet. Res.* 40: 61-65.
- Young, L.G. R.B. Miller, D.E. Edmeades, A. Lun, G.C. Smith and G.J. King. 1977. Selenium and vitamin E supplementation of high moisture corn diets for swine reproduction. *J. Anim. Sci.* 45: 1051-1060.

## SUMMARY

## Summary

The main nutritional goal for lactating sows is to optimize lactation weight loss and improve milk production (or milk nutrients production) and litter performance. Therefore, it is important to study the effect of dietary components on the amount and composition of milk. For this reason the fat and protein mobilization in sow's body (energy metabolism of sows) need to be known also.

Results from the literature indicate that dietary energy intake can play an important role in altering these traits. Because gilts consume about 15% less energy during lactation compared to multiparous sows there is less possibility to improve the lactation energy intake by increasing daily feed consumption. Another possibility may be to increase the energy density of the diets by the addition of fat.

The dietary fat level can be also an important component for vitamin E requirement. Vitamin E is known to act as an antioxidant. This vitamin is a fat-soluble. Fat may therefore facilitate the vitamin E absorption and therefore, it may influence the health status of the animals and probably of the performance of sows and piglets.

From the literature it was concluded (General Introduction), that the effect of fat addition to the sow's diet on the practical traits (weight of sows and piglets, milk components, milk production, survival of piglets) has been studied extensively. Data in the literature showed that adding fat to sow diets improved pig survival in several studies. However, the improvement is small and has not been observed in all experiments. Data also showed that fat supplementation had no consistent effect on milk production of sows. From the literature it was also concluded that there is only very limited information on the energy metabolism of lactating sows fed various levels of dietary fat.

Results from different literature sources suggested that dietary vitamin E can increase the  $\alpha$ -tocopherol concentration in serum colostrum and milk. The studies with chicken, rats, mice, weaning and growing pigs sometimes indicated that vitamin E can influence the immune system of animals. However, there is only a limited number of systematic studies on the effect of dietary vitamin E on immune response in lactating sows and suckling piglets. Results available showed only minor positive vitamin E effects on reproduction performance and on milk production of sows.

Therefore, in the present thesis the effect of two nutrients (dietary fat and vitamin E) was studied on the energy metabolism and lactation performance as well as on the amount and composition of milk of primiparous sows (Chapters 1,2 and 3). The effect of dietary vitamin E and different types of dietary fat in the sow's diet, on the performance and on the immune system of the lactating sows and their piglets was also studied (Chapters 4, 5 and 6).

In two experiments, a total of 63 primiparous PIC (Pig Improvement Company, England) hybrid

sows were used to study the effect of different fat and vitamin E levels in the lactation diet on the energy metabolism, and milk production of sows and on the performance of sows and their piglets during lactation.

In experiment 1, the major difference in energy sources in the lactation diets were tapioca starch or animal fat. Fifteen sows received the low-fat diet (starch and fat content: 396 and 43 g/kg DM, respectively) and 16 sows were fed moderate-fat diet (starch and fat content: 286 and 75 g/kg DM, respectively) during 4 weeks of lactation.

In experiment 2, 200 g/kg cornstarch was substituted by animal fat on the basis of expected net energy content. Sixteen sows were fed during 4 weeks of lactation a low-fat diet (starch and fat content: 418 and 37g/kg DM, respectively) and 16 were fed a high-fat diet (starch and fat content: 266 and 125 g/kg DM, respectively). Vitamin E (as  $\alpha$ -tocopherol) contents of feeds in experiment 1 were 14 and 126 mg/kg diet, respectively and in experiment 2, 22 and 151 mg/kg diet respectively. In both experiments, energy and nitrogen balances of sows were measured in respiration chambers between days 18 and 25 of lactation. Heat production (sows plus piglets per chamber) was determined indirectly by measurement of the  $\text{CO}_2$  produced and the  $\text{O}_2$  consumed. The milk production of sows was measured on five separate days during lactation by weighing the litters (several times per day) before and after suckling.

In another series of experiments, a total of 45 PIC gilts (7-8 animals per treatment) were used to study the effect of different levels of dietary vitamin E (13, 48 and 136 mg  $\alpha$ -tocopherol per kg feed respectively) and fat source (5% sunflower oil or animal fat) in pregnant and lactating sows diets on lactation performance of sows and performance of piglets. From the total number of 45, 36 gilts (six gilts per treatment) were used to study the effect of dietary vitamin E and fat source on  $\alpha$ -tocopherol concentration in serum and on cell-mediated and humoral immune response of lactating sows and their piglets. The  $\alpha$ -tocopherol concentration in colostrum and milk was also measured. Gilts each received one of six diets throughout pregnancy and during 4 weeks of lactation.

The blood samples from sows and piglets were analysed for  $\alpha$ -tocopherol concentration, total number of leucocytes and T- and B-lymphocyte counts. In blood (from sows and piglets) lymphocyte stimulation with concanavaline A, lysozyme activity and immunoglobulin concentrations were also measured. In milk samples,  $\alpha$ -tocopherol and immunoglobulin concentrations were determined at farrowing and also at weaning. After weaning all piglets received identical diets (20 mg  $\alpha$ -tocopherol/kg diet). One week after weaning pigs were immunized (i.m. with ovalbumin and tetanus toxoid) and antibody production was measured.

From the results of experiments reported in the present thesis the following main conclusions were drawn:

1. A high level of fat in the lactation diet (125 g/kg DM) decreased the daily heat production of sows compared to the low fat level (37 g fat/kg DM). This lower heat production can have a beneficial effect on energy intake of sows, especially at high ambient temperatures (Chapter 1 and 2).
2. Daily milk-related heat production was lower for sows fed a high level of dietary fat compared to the sows fed a diet in which the dietary fat level was lower and dietary starch higher (General Discussion).
3. The high respiratory quotients and the calculated amount of milk fat from non-fat nutrients in the diet, indicated that sows fed low (37 or 43 g fat/kg DM) or a moderate-fat diet (75 g fat/kg DM) needed to synthesize more milk fat from other dietary sources (i.e. carbohydrates) than from fat, compared to high-fat diet (125 g fat/kg DM), (Chapter 2 and General Discussion).
4. The partial efficiency of milk energy production from metabolizable energy from dietary fat was estimated to be from 89 to 94 % (General Discussion).
5. The efficiency of milk production from ME-feed above maintenance requirement, was improved significantly when sows were fed high level of dietary fat during lactation (Chapter 1).
6. The moderate level of dietary fat (75 g fat/kg DM) showed no difference in the metabolic rate of lactating sows compared to the low level (43 g fat/kg DM). Also, the energy metabolism of sows was not influenced by the different levels of dietary vitamin E (Chapter 1 and 2).
7. The milk production of sows was not improved by high level of dietary fat nor by different levels of dietary vitamin E (Chapter 3 and 4).
8. The lactation performance of piglets was not clearly influenced by the different levels of dietary fat nor by the vitamin E in the sow's diet (Chapter 3 and 4).
9. The high level of vitamin E in the sow's diet including either sunflower oil or animal fat significantly increased the serum  $\alpha$ -tocopherol concentration in sows just after farrowing and at weaning. The  $\alpha$ -tocopherol concentration in piglet serum at only one week of age was increased significantly by the high level of dietary vitamin E in the sow's diet (Chapter 5 and 6).
10. The combination of high dietary vitamin E with animal fat gave the highest  $\alpha$ -tocopherol concentration in colostrum. At weaning,  $\alpha$ -tocopherol in milk fat was highest in both fat groups with high dietary vitamin E (Chapter 5).

11. We did not demonstrate any effect of the cell-mediated immunity of lactating sows by the dietary vitamin E levels. The humoral immune system of sows was only slightly affected by the combination of vitamin E and fat given (Chapter 5).
12. The cell-mediated immunity of suckling and weaned piglets was not affected by different levels of vitamin E or types of dietary fat in the sow's diet. Assuming that an increase of antibody production (against ovalbumin) is beneficial for immune reactivity, the high level of vitamin E in the sow's diet during lactation can improve the immune status of weaned piglets one week after immunization (Chapter 6).
13. The medium level of vitamin E (48 mg/kg) in the pregnancy and lactation diet can increase the lysozyme concentration in piglets at one week of age, which indicates a higher lysozyme activity (Chapter 6).

The results of our studies show that a high level of fat in the sow's lactation diet can influence the energy metabolism of sows and the energetic efficiency of milk production. The high dietary fat level improved the milk fat output.

The high level of dietary vitamin E in the pregnancy and lactation diet had no consistent effect on the cell-mediated and humoral immune response of lactating sows. The results of present studies suggest that there may be reason to adjust vitamin E levels in sow's diets to improve some immunological variables in piglets. The fat sources in the sow's diet had no consistent effect on the piglets immunological parameters.

## **SAMENVATTING**

## Samenvatting

Een optimale voeding van lakterende zeugen is voor wat betreft melkproductie en gewichtsverlies gericht op het voorkómen van negatieve gevolgen voor vruchtbaarheid, levensduur en biggenproductie. Daarom is de mogelijke invloed van de voedersamenstelling op de melkproductie en op de melksamenstelling een belangrijk aspect. De voersamenstelling bepaalt immers mede de hoeveelheden vet en eiwit, die behalve uit voer uit het lichaam van de zeug voor de melkproductie moeten worden gemobiliseerd.

Uit de literatuur blijkt dat energieopname door lakterende zeugen uit het voer een rol kan spelen bij de melksamenstelling. Eerste worps zeugen nemen gemiddeld 15% minder voer op dan meerdere worps zeugen. Daarom is er bij deze dieren ook bijna geen mogelijkheid om de energieopname te verhogen door het verstrekken van meer voer. Door verhoging van de energieconcentratie in het voer door toevoeging van vet kan mogelijk wel de voeropname verhoogd worden.

Vet is niet alleen belangrijk voor de energievoorziening. Ook vitamine E als vetoplosbaar vitamine is een bestanddeel van vet in het rantsoen. Vitamine E kan omgekeerd ook invloed op vet uitoefenen omdat het een natuurlijk antioxidant is. Vitamine E en vet kunnen mogelijk dus elkaars verteerbaarheid en dus ook hun effect op het dier beïnvloeden. Omdat vitamine E in verband kan worden gebracht met gezondheid en weerstand is een interactie van vet met vitamine E hiervoor ook een belangrijk aspect van onderzoek.

In de algemene inleiding is een overzicht gegeven met betrekking tot de literatuur aangaande het effect van vettoevoeging aan voeders voor zeugen. De algemene conclusie uit de literatuur is dat er veel praktische proeven met vettoevoeging aan voer voor drachtige en lakterende zeugen zijn uitgevoerd. Gewichtsverandering van zeug en biggen, melkproductie en melksamenstelling alsook mortaliteit zijn uitgebreid onderzocht. In sommige studies werd door extra vet in het voeder een toename van het aantal overlevende biggen gevonden. Deze toename was niet erg groot en dit werd bovendien niet in alle onderzoeken gevonden.

De studies toonden geen systematisch effect aan van extra vet in het voer op de melkproductie. In sommige rapporten werd bovendien geopperd dat er een invloed kan zijn van de vethoeveelheid in het rantsoen of voeder op de energiestofwisseling van lakterende zeugen.

Resultaten uit verschillende proeven suggereren ook dat het vitamine E gehalte in het voer het vitamine E gehalte in bloedserum en in colostrum en melk kan verhogen. Onderzoekingen met muizen, ratten, kippen en varkens toonden soms een positief effect aan van vitamine E in het rantsoen op het immuunsysteem. Bij lakterende zeugen en biggen is echter nog nauwelijks systematisch onderzoek hiernaar verricht. De studies suggereren ook een klein positief effect van vitamine E op reproductie en melkproductie.

In de in dit proefschrift beschreven onderzoeken werd het effect van vet en van vitamine E op de energiestofwisseling, de melkproductie en de melksamenstelling bestudeerd bij eerste worpszeugen (Hoofdstukken 1, 2 en 3). In een andere serie proeven (Hoofdstukken 4, 5 en 6) werd de invloed van het soort vet (plantaardig of dierlijk) in samenhang met vitamine E op enkele immuunkenmerken van de zeug en van biggen bestudeerd.

In de twee eerste proeven met in totaal 63 eerste worps zeugen werd het effect van verschillend vet en vitamine E-niveau in het voer bestudeerd. Er werden metingen verricht met betrekking tot de energiebalans, de melkproductie en de melksamenstelling. Ook werd de gewichtsonwikkeling van de dieren gedurende de laktatie bestudeerd.

In experiment 1 werd het verschil onderzocht tussen rantsoenen met zetmeel (uit tapioca) of dierlijk vet als energiebron. Vijftien zeugen kregen een laag vet rantsoen (zetmeel en vetgehalte resp. 396 g en 43 g per kg droge stof); zestien andere dieren kregen meer vet en minder tapioca zetmeel (resp. 75 g vet en 286 g zetmeel per kg droge stof) in het rantsoen gedurende een laktatieperiode van vier weken. Het vitamine E-gehalte in experiment 1 was resp. 14 en 126 mg per kg voer in de laag en hoog vitamine E groep.

In experiment 2 werd 200 g maiszetmeel per kg voer op basis van verwachte netto energiegehalte vervangen door dierlijk vet. Zestien zeugen kregen een laag vetrantsoen (resp. 418 g en 37 g zetmeel en vet per kg droge stof). Zestien andere zeugen ontvingen een rantsoen met een hoog vetgehalte en een lager zetmeelgehalte (resp. 125 g vet en 266 g zetmeel per kg droge stof).

Per kg voer werd 22 mg en 151 mg vitamine E verstrekt aan resp. de laag en hoog vitamine E niveau dieren. In beide proeven werd tussen 18 en 25 dagen laktatie de energiebalans gemeten. De warmteproductie werd berekend uit de gemeten waarden van  $O_2$ -opname en  $CO_2$ -uitscheiding. De melkproductie werd gedurende 5 dagen gemeten door de biggen enkele keren per dag voor en na het zogen te wegen.

In de andere serie proeven werden 45 zeugen (7 of 8 dieren per behandeling) gebruikt om de effecten van verschillende niveaus van vitamine E (resp. 13, 48 en 136 mg  $\alpha$ -tocopherol per kg voer) en het effect van de vetbron (resp. zonnebloemolie en dierlijk vet) te onderzoeken. Het effect werd onderzocht bij zeugen tijdens dracht en laktatie met als onderzoekscriteria de melkproductie en de ontwikkeling van de biggen. Van deze 45 zeugen werden er tevens 36 gebruikt om de effecten van vetbron (plantaardig of dierlijk) en vitamine E-niveau (laag, midden en hoog) op het vitamine E niveau in het serum en op de cellulaire en humorale immuniteit te meten. Deze laatste aspecten werden zowel bij zeugen als bij biggen gemeten. Ook vitamine E-gehalten in colostrum en in melk werden geanalyseerd.

Bloedwaarden van zeugen en biggen werden geanalyseerd op vitamine E, totaal leucocyten en op de

T- en B-lymphocyten. In het bloed van zeugen en biggen werd, behalve de lymphocytstimulatie door concavaline tevens de lysosyme activiteit en de immunoglobuline-gehalten gemeten. Vlak na afbiggen en bij het spenen werden ook vitamine E- en immunoglobuline-gehalten gemeten. Na het spenen ontvingen alle biggen eenzelfde voer met 20 mg  $\alpha$ -tocopherol per kg. Een week na het spenen werden de dieren geïmmuniseerd met ovalbumine en tetanustoxoid en de antilichaamproductie hiertegen werd een week later gemeten.

De resultaten leiden tot de volgende conclusies:

1. Een hoog vetniveau in het laktatie voer (125 g/kg droge stof) verlaagt de warmteproductie van zeugen in vergelijking met een laag vetniveau (37 g/kg droge stof). Er werd geconcludeerd dat dit gunstig kan zijn voor de energie-opname doordat het hoge vetniveau een minder hoge hittebelasting geeft bij hoge temperatuur (Hoofdstukken 1 en 2).
2. De dagelijkse warmteproductie die ontstaat bij melksynthese is verlaagd bij dieren op een hoog vetrantsoen (Hoofdstuk "Algemeen Discussie").
3. De verschillen in respiratiequotiënten (verhouding  $\text{CO}_2$  geproduceerd/ $\text{O}_2$  geconsumeerd) geven aan dat dieren op hoog vet dieet (125 g/kg droge stof) veel minder vet hoeven te synthetiseren uit nutriënten anders dan vet dan de dieren op een laag of midden vet dieet (37 of 43 g/kg droge stof en 75 g/kg droge stof), (Hoofdstuk "Algemeen Discussie").
4. De partiële efficiëntie voor de productie van melkenergie uit de verteerbaar energie uit vet werd berekend als 89 tot 94 % (Hoofdstuk "Algemeen Discussie").
5. De efficiëntie van de productie van melkenergie uit omzetbare energie boven onderhoud werd significant verhoogd bij meer vet in het rantsoen (Hoofdstuk 1).
6. Tussen midden vetniveau en laag vetniveau werden geen duidelijke verschillen in stofwisseling en in efficiëntie gevonden. Het vitamine E-niveau had geen enkele invloed op de energiestofwisseling van zeugen noch bij laag, midden of hoog vetniveau (Hoofdstukken 1 en 2).
7. De melkproductie van zeugen werd niet beïnvloed door het vetniveau in het rantsoen (Hoofdstukken 3 en 4). Het vetgehalte in de melk was enigszins verhoogd bij meer vet in het rantsoen.
8. De groei van biggen tijdens de lactatie was niet duidelijk beïnvloed door vitamine E-niveau in het voer van de zeug (Hoofdstukken 3 en 4).
9. Een hoog vitamine E-niveau in rantsoenen met veel plantaardig of dierlijk vet voor drachtige en lakterende zeugen verhoogde het serum tocopherolgehalte duidelijk bij de zeugen zelf zowel bij werpen als bij spenen. Bij biggen was deze verhoging eveneens aanwezig en was het duidelijkst toen de dieren een week oud waren (Hoofdstukken 5 en 6).

10. De zeugen die voer ontvingen met een hoog vitamine E-gehalte en met dierlijk vet gaven colostrum met het hoogste gehalte aan  $\alpha$ -tocopherol (Hoofdstuk 5). Bij spenen was het  $\alpha$ -tocopherol-gehalte in melkvet het hoogst in beide vetgroepen met hoog vitamine E (Hoofdstuk 5).
11. Er werd geen effect gevonden van vitamine E-niveau op de cellulaire immuniteit van zeugen. De humorale immuniteit werd in beperkte mate beïnvloed door de verstrekte combinatie van vitamine E en vet (Hoofdstuk 5).
12. Bij de biggen werd geen effect van vitamine E en ook niet van het soort vet in het rantsoen op de cellulaire immuniteit gevonden. Een hoger vitamine E-gehalte in het zeugenrantsoen kan de titer tegen ovalbumine na het spenen verhogen (Hoofdstuk 6).
13. Een gemiddeld vitamine E-niveau van 48 mg/kg voer gedurende de dracht en laktatie kan de lysozyme concentratie en activiteit bij biggen van een week oud verhogen (Hoofdstuk 6).

De resultaten van deze studies tonen aan dat een hoog vetniveau in het rantsoen van zeugen de energiestofwisseling positief kan beïnvloeden door verhoging van de efficiëntie van melkvorming. Een hoog vetniveau in het voer verhoogde het vetgehalte in de melk enigszins. Een hoog vitamine E-niveau had geen invloed op de energiestofwisseling en ook geen consistent effect op de cellulaire en humorale immuunrespons van lakterende zeugen. Uit dit onderzoek blijkt dat er mogelijk aanleiding is het vitamine E-gehalte in zeugen-voer nader aan te passen, om immunologische parameters bij biggen te verbeteren.

## **Curriculum vitae**

László Babinszky was born September 1, 1950 in Budapest, Hungary. He received the diploma from Agricultural University in Debrecen (Hungary), in 1974. After completing his studies he joined the Research Institute for Animal Nutrition in Herceghalom (near Budapest), where he is a research worker. In 1977, he earned the university doctor degree in Hungary. He conducted several series of studies related to swine nutrition.

From 1984 to 1985 he has been working in the Department of Animal Nutrition of Agricultural University in Wageningen and in the Department of Biochemistry and Animal Physiology of Institute for Livestock Feeding and Nutrition (IVVO) in Lelystad in the Netherlands. During this period his research program has included the development of a new in vitro method for prediction of the digestible crude protein content in pig feeds. He has also studied the ileal digestibility of nutrients in growing pigs.

From 1988 to 1992 he has been working in the Department of Animal Nutrition of Agricultural University in Wageningen.

## Major scientific publications

L. Babinszky

Babinszky, L. 1977. Effect of feeding methods on digestibility of nutrients and on N-retention in growing and fattening pigs [in Hungarian]. *Thesis, Agric. University of Mosonmagyaróvár, Hungary.*

Babinszky, L. and J. Gundel. 1978. Effect of feeding methods on the performance of pigs. I. Effect of feeding methods on digestibility of nutrients and on N-retention in growing finishing pigs [in Hungarian, engl. abstr.]. *Allattenyésztés* 4: 345-352.

Gundel, J. and L. Babinszky. 1978. Effect of feeding methods on the performance of pigs. II. Effect of feeding methods on the fattening performance [in Hungarian, engl.abstr.] *Allattenyésztés* 5: 397-403.

Gundel, J. and L. Babinszky. 1979. Einfluß der Futtermittelaufnahme auf Nährstoffverdauung, Stickstoffumsatz und Leistung der Mastschweine [in German]. *Tag.Ber., Akad.Landwirtsch.-Wiss., Berlin*; 165: 91-98.

Babinszky, L. 1979. Einfluß der Futtermittelaufnahme auf den Eiweiß- und Fettansatz in Versuchen mit HUNGAHYB Schweinen [in German, engl. abstr.]. *EAAP 30th Ann. Met., Harrogate, Paper P5.17.*

Gundel, J., S. Szentmihályi, L. Babinszky, E. Votisky, and P. Ugody. 1979. Effect of different daily protein and energy intakes on performance of growing and fattening pigs [in Hungarian]. *ATK-Közlemények, Gödöllő*, 162-167.

Gundel, J. L. Babinszky and E. Votisky. 1981. Effect of threonine and tryptophane supplementation of cereal diets on the performance of growing-finishing pigs. *6th Int. Amino Acid Symp. Proc. Poland, Paper: IV/10.*

Gundel, J., L. Babinszky, A. Régius, L. Vigh and M. Kemenes. 1981. Copper as a growthpromoter used on cereal diets in growing-finishing pigs. *Int. Conf. on Feed Additives, Budapest, Proc. 1: 145-148.*

Babinszky, L., J. Gundel, L. Dégen, and E. Votisky. 1986. Effect of different energy intake on the performance of pregnant and lactating sows and on protein and fat deposition in sows and foetuses [in Hungarian]. *ATK-Közlemények, Gödöllő*, 291-295.

Gundel, J., L. Babinszky L. 1986. Ferkelaufzuchtversuch mit Flavophospholipol, Salinomycin-Natrium und Zink-Bacitracin in Ungarn [in German]. *Landwirt. Forschung* 3: 215-217.

Babinszky, L., J.M. van der Meer, H. Boer and L.A. den Hartog. 1987. Prediction of protein digestibility in pigs. *5th Int. Symp. on Protein Metabolism and Nutrition*, Rostock, Germany. 46.

Beyer, M., L. Hoffmann, R. Schiemann, W. Jentsch, Gh. Burlacu, M. Iliescu, E.A. Machajew, L. Babinszky, J. Gundel, L. Lassota, M. Walach-Janiak and L. Zeman. 1987. Biological basics for the factorial derivation of the energy and protein requirement for pregnant and lactating sows and suckling piglets. *5th Int. Symp. on Protein Metabolism and Nutrition*, Rostock, Germany.

Babinszky, L. und J. Gundel. 1987. Die Anwendung der Wachstumsförderer in der Schweinefütterung in Ungarn [in German] In: *Proc. Int. Symp. "Vitamin und Ergotropika- Einsatz und Forschung"*, Reinhardsbrunn, Germany, 250-255.

Gundel, J. and L. Babinszky. 1988. Digestibility of feed in pig experiments [in Hungarian, engl. abstr.] *Allattenyésztés és Takarmányozás* 1: 73-80.

Fébel, H. and L. Babinszky. 1988. General anaesthesia in growing pigs using the combination of ketamine, fentanyl and droperidol [in Hungarian, engl. abstr.]. *Magy. All. Lapja* 10: 603-608.

Kubovics, E., H. Fébel and L. Babinszky. 1989. Ileal cannulation by a simple T-fistula for the digestion system physiological examinations in pigs [in Hungarian, engl. abstr.]. *Allattenyésztés és Takarmányozás* 1: 69-73.

Babinszky, L., J.M. van der Meer, H. Boer, L.A. den Hartog. 1990. An in vitro method for prediction of the digestible crude protein content in pig feeds. *J. Sci. Food Agric.* 50: 173-178.

Babinszky, L., D.J. Langhout, M.W.A. Verstegen, L.A. den Hartog, P. Joling and M. Nieuwland. 1991. Effect of alpha-tocopherol and dietary fat source on some blood and immunological variables in lactating sows. *Anim. Prod.* 52: 367-375.

Babinszky, L., D.J. Langhout, M.W.A. Verstegen, L.A. den Hartog, P. Joling and M. Nieuwland. 1991. Effect of vitamin E and fat source in sows' diets on immune response of suckling and weaned piglets. *J. Anim. Sci.* 69: 1833-1842.

Szelényi, M., L. Babinszky, I. Smied, H. Fébel, E. Votisky, L. Dinnyés and A. Pataki. 1991. Ileal and fecal digestibility of the nutritive substances of feeds in growing pigs [in Hungarian, engl. abstr.]. *Allattenyésztés és a Takarmányozás* 5: 441-450.

Babinszky, L., M.W.A. Verstegen, L.A. den Hartog, W. van der Hel, T. Zandstra and J.T.P. Dam. 1991. Effect of dietary carbohydrate and fat on energy- and nitrogen balances and milk production of lactating sows. In: C. Wenk and M. Boessinger (Eds) *Energy Metabolism of Farm Animals*, EAAP Publications. p. 268-271. ETH-Zürich, Switzerland.

Babinszky, L., M.W.A. Verstegen, L.A. den Hartog, W. van der Hel, T. Zandstra, E.M.W. van den Elsen and J.T.P. van Dam. 1991. Effect of dietary fat level and vitamin E on energy- and nitrogen balances of primiparous lactating sows. *J. Anim. Sci.* (submitted for publication).

Babinszky, L., M.W.A. Verstegen, L.A. den Hartog, T. Zandstra P.L. van der Togt and J.T.P. van Dam. 1991. Effect of dietary fat level in the lactation diet on the performance of primiparous sows and their piglets. *Anim. Prod.* (submitted for publication).

Babinszky, L., M.W.A. Verstegen, H.A. Brandsma, W. van der Hel and L.A. den Hartog. 1991. Metabolic rate of primiparous lactating sows and suckling piglets as affected by dietary fat level and vitamin E. *J. Anim. Sci.* (submitted for publication).

Babinszky, L., D.J. Langhout, M.W.A. Verstegen, L.A. den Hartog, T. Zandstra, P.L.G. Bakker and J.A.M. Verstegen. 1992. Dietary vitamin E and fat source and lactating performance of primiparous sows and their piglets. *Livest. Prod. Sci.* **30**: 155-168.