Pre- and postnatal transfer of vitamins E and C to piglets in sows supplemented with vitamin E and vitamin C

A. Pinelli-Saavedra\textsuperscript{a,b}, J.R. Scaife\textsuperscript{b,*}

\textsuperscript{a}Department of Animal Nutrition, Centro de Investigación en Alimentación y Desarrollo, A.C. Hermosillo, Sonora, México
\textsuperscript{b}Department of Agriculture and Forestry, University of Aberdeen, Aberdeen AB24 4FA, UK

Received 4 October 2004; received in revised form 25 February 2005; accepted 4 May 2005

Abstract

This experiment investigated the effects of dietary supplementation of vitamin E and vitamin C on sow reproductive performance and transfer of vitamin E to piglets via the placenta, colostrum and milk. A total of 58 sows were allocated to the following treatment diets: control, vitamin C 1 g/day, vitamin C 10 g/day, vitamin E 200 mg/kg feed, vitamin E 400 mg/kg fed, and vitamins E and C (vitamin E 200 mg/kg feed + vitamin C 1 g/day). Piglet weight on days 0 and 21, litter size, piglets live on d-0 and d-21 were recorded. Vitamin E and vitamin C were determined in sow serum throughout the experiment (d-0, d-60, d-103 and 21 days after farrowing (F + 21)), in colostrum, milk and piglet serum (cord blood) and vitamin E in placenta. Vitamin E and vitamin C had no effect ($P \geq 0.05$) on piglet growth performance and sow reproductive performance. Vitamin E supplementation significantly increased the vitamin E content of sow serum, colostrum, milk and piglet serum at birth; effects of vitamin C supplementation were less consistent. Vitamin E content in piglet serum at birth was significantly correlated ($r = 0.39 \ (P < 0.05)$) with the vitamin E content of placenta, and also with sow serum vitamin E concentration on day 103, $r = 0.52 \ (P < 0.01)$. Placental vitamin E concentrations were low but were increased by dietary vitamin E supplementation. These results provide evidence for only limited placental transfer of vitamin E but in utero concentration of vitamin C on the foetal side of the placenta. For both vitamins the efficiency of placental transfer decreased as maternal serum vitamin concentrations increased. The main supply of these vitamins to the newborn piglet was via the mammary gland rather than the placenta.

© 2005 Elsevier B.V. All rights reserved.

Keywords: Pig; Vitamin E; Placenta; Reproductive performance; Transfer; Colostrum; Milk

1. Introduction

There is conflicting evidence on the effects of vitamin E and vitamin C supplementation on reproductive performance in sows. Ullrey (1981), Hardy and Frappe (1982), and Mahan et al. (1974) suggested that in order to see positive effects of supplementation...
with vitamin E on litter size and number born alive, sows should be supplemented for more than one parity and/or that vitamin E should be supplemented with selenium. In several studies, increased litter size and reduced preweaning piglet mortality resulted from increasing sow dietary vitamin E intake during gestation (Cline et al., 1974; Mahan, 1991) or from intramuscular injections of vitamin E (Chavez and Paton, 1986; Migdal and Kaczmarczyk, 1993; Mavromatis et al., 1999). Supplementation of sows with 1, 2 or 10 g/day vitamin C for 1 week before farrowing had no effect on litter size, number still born and weight at birth, whereas supplementation with 1 g/day throughout gestation has been reported to increase litter size by 1 piglet per litter (Carmona-Garcia, 1983). Little is known about the transport of vitamin E via the placenta in any species and the vitamin E content of placenta. Malm et al. (1976) reported that the concentration of serum α-tocopherol in unsuckled newborn piglets was several fold higher than that of their dams, strongly suggesting efficient placental transfer of vitamin E even when dams were not supplemented with the vitamin. However, most reports have suggested that, prior to nursing, the α-tocopherol concentration in the serum of neonatal pigs is low whether the dam is provided with adequate (44–50 mg vitamin E/kg feed, NRC, 1998) or supplemented dietary levels of vitamin E during gestation (Young et al., 1977; Loudenslager et al., 1986; Babinszky et al., 1991; Farnworth et al., 1995; Hidiroglou et al., 1995). The low plasma and tissue levels of α-tocopherol in newborn pigs suggest a low rate of vitamin E transfer across the placenta which is not influenced by dietary supplementation of the sow during pregnancy. Mahan (1991) reported that dietary vitamin E fed to the pregnant sow does not effectively transfer to the foetus but the α-tocopherol concentration of the neonate serum before nursing increased as the supplementary level of vitamin E in sow diets increased. In other species such as dairy calves and lambs, transfer of vitamin E via the placenta has been reported to be low (Hidiroglou et al., 1969; Van Suan et al., 1989; Nockels, 1991; Njeru et al., 1994). Foetal pigs have the capacity to synthesise vitamin C during early developmental stages but lose the ability as pregnancy advances (Ching et al., 2001). Yen and Pond (1983) and Chavez (1983) demonstrated the occurrence of placental transfer of vitamin C in pigs and it has been shown that near term foetal plasma vitamin C concentration may be several times higher than that in maternal plasma (Wegger and Palludan, 1984). This process is important since the neonatal pig is unable to synthesise vitamin C during the first week of life and is dependent on supply via placental transfer, and vitamin C in colostrum and milk (Bowland et al., 1949; Chavez, 1983; Hidiroglou and Batra, 1995). After weaning the pig becomes entirely dependent on endogenous synthesis of the vitamin to meet its vitamin C needs and there is evidence to suggest that the rate of synthesis may be inadequate during adverse environmental stress, after diseases and during other periods of stress such as weaning (Warriss, 1984). The aims of this study were to determine the effects of vitamin E and vitamin C supplementation of sow diets on reproductive performance of sows, survival and growth of piglets and placental transfer of vitamins E and C. The work was carried out under commercial conditions on a farm in Northwest México.

2. Materials and methods

The experiment was carried out during the summer (June–September) on a pig farm in Sonora, México and was carried out under commercial pig production conditions.

2.1. Animals and treatments

The sows used in this study were multiparous crossbred sows mainly 90% Large white × Landrace and 10% Duroc, with a range of parities from 2 to 7, and were approximately 200 kg live weight and 2–2.5 years of age at the time of insemination. When sows were allocated to the different dietary treatments, parity was taken into account in an attempt to balance parity across treatments. Parity ranged from 3.3 to 5.7. The following diets were fed throughout the experiment: diet 1, Control (commercial diet containing 36 mg vitamin E/kg feed); diet 2, Control + Vitamin C (1 g/day) (C1); diet 3, Control + Vitamin C (10 g/day) (C10), diet 4, Control + Vitamin E (200 mg/kg feed) (E200); diet 5, Control + Vitamin E (400 mg/kg feed) (E400); diet 6, Control + Vitamin E (200 mg/kg feed) + Vitamin C (1 g/day) (E+C). The experiment started when the sows were artificially inseminated. At this
time 78 sows were allocated randomly in groups of 13 to the 6 dietary treatments. After 1 month 20 sows which were not pregnant were removed and the study continued with those confirmed pregnant. The experiment lasted until weaning (21 ± 3 days). The final number of sows that participated in this study was 58.

2.2. Diet formulation

The diets were formulated to meet the Nutrient Requirements of Swine (NRC, 1998). All the experimental diets were formulated to be adequate in vitamins, trace minerals and major elements. During pregnancy sows were fed, once daily, a gestation diet (Table 1) calculated to provide 26.6 MJ metabolizable energy (ME) per day (2.2 kg feed per day per sow). Approximately 21 days before farrowing sows were given, once daily, a prepartum diet (Table 1) calculated to provide 29 MJ ME (2.2 kg feed per day per sow). After farrowing, sows were fed, twice daily, 2.5 kg of a lactation diet (Table 1) providing a daily ME intake of 66.5 MJ. Water was available ad libitum during pregnancy and lactation.

The vitamin E (ROVIMIX® E-50 Adsorbate, ROCHE; 50% activity) and vitamin C (Vitamin C Type EC ROCHE, ascorbic acid, crystalline form, 97% activity) were added daily to the diets at the time that animals were fed.

2.3. Growth and reproductive performance

The following data were recorded for each litter immediately postpartum: number of live and stillborn piglets. Piglet weight was recorded at birth and on the day of weaning (day 21 ± 3).

2.4. Collection of samples

Blood samples were taken from sows by jugular venepuncture at the time of allocation to diets (day 0) and days 60, 103, and 21 ± 3 days after farrowing (F + 21). Blood samples were collected from all piglets in each litter immediately after birth (mixed arterial and venous cord blood). Approximately 50 ml of colostrum and milk from each sow was collected by hand from all functional nipples on day 0 and milk on day 21 ± 3. Samples were immediately placed in an ice bath and transported to the laboratory. Samples of placenta (approximately half of the placenta, taken immediately after farrowing) were also collected onto ice and frozen at −20 °C as quickly as possible for vitamin E analysis. Prior to analysis, serum and colostrum and milk were stored at −70 °C.

2.5. α-Tocopherol analysis

α-Tocopherol was extracted from serum as described by Hess et al. (1991), from placenta tissue as described Onibi et al. (1998) and from colostrum and milk as described by Hidiroglou (1989).

α-Tocopherol was measured by high-performance liquid chromatography (HPLC) with a Varian HPLC system (Palo Alto, CA) and a Shimadzu RF-535 fluorescence detector (Tokyo, Japan) set at an excitation wavelength of 296 nm and an emission wave-
length of 326 nm. Separation was achieved using a Partisil Si (250 mm × 4.6 mm) column (Alltech, Carnforth, United Kingdom). The mobile phase was n-hexane and 1,4-dioxane, programmed to change linearly from 95:5 (vol/vol) to 75:25 (vol/vol) over a 7.5-min run time.

2.6. Vitamin C analysis

Vitamin C was extracted from serum as described by Mezzetti et al. (1995) and measured by high-performance liquid chromatography (HPLC) using a Beckman HPLC system and UV–Visible detector, model 168. Separation was achieved using a μBondapak™ NH2 ion exchange column. The mobile phase was acetonitrile/0.05 M KH2PO4. Ascorbic acid was extracted from colostrum and milk and measured using the colorimetric method described by Gunter et al. (1980).

3. Statistical analysis

Data were subjected to analysis of variance (ANOVA) using the Minitab Statistical Package (v. 12.0, Minitab, Inc., PA, USA) to determine the overall effect of dietary treatments. Significant differences between treatment means were determined by Tukey’s test (P < 0.05). Analysis of covariance (ANCOVA) was used to assess the effect of parity on the analysis of the reproductive performance of sows and growth performance of piglets. No effect of parity was observed. Reproductive performance of sows was analysed on the basis of mean litter performance. For statistical analysis of blood parameters in samples obtained from sows and piglets, ‘repeated measures’ ANOVA was employed. The relationship between vitamin E concentrations in piglet serum with placenta, and sow serum on d-103 with piglet serum on d-0, was assessed by linear regression analysis.

4. Results

4.1. Reproductive performance

There were no significant effects of treatment on total number of piglets born, number of piglets alive on day 0 and day 21, piglet weight on day 0 and day 21 and live weight gain between the control and groups supplemented with vitamin E and/or vitamin C (Table 2). Covariate analysis showed that weight on day 0 and litter size at birth had no significant effect on subsequent piglet performance.

4.2. Vitamins E and C in sow serum

Covariate analysis showed that although there were significant differences between vitamin E concentrations on day 0, this had no effect on subsequent changes in serum vitamin E concentrations. On subsequent sampling days the vitamin E concentration in

<table>
<thead>
<tr>
<th>Treatments</th>
<th>n</th>
<th>Parity</th>
<th>Total piglets/litter</th>
<th>D-F+0</th>
<th>Live D-F+21</th>
<th>D-F+0 (kg)</th>
<th>D-F+21 (kg)</th>
<th>LWG (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>10</td>
<td>3.3 (0.4)</td>
<td>9.9 (1.0)</td>
<td>9.6 (1.0)</td>
<td>8.0 (0.9)</td>
<td>1.4 (0.1)</td>
<td>5.7 (0.5)</td>
<td>4.2 (0.3)</td>
</tr>
<tr>
<td>C 1</td>
<td>9</td>
<td>5.0 (0.8)</td>
<td>8.8 (0.9)</td>
<td>8.6 (0.3)</td>
<td>7.4 (0.6)</td>
<td>1.5 (0.1)</td>
<td>6.2 (0.3)</td>
<td>4.6 (0.3)</td>
</tr>
<tr>
<td>C 10</td>
<td>9</td>
<td>5.2 (0.7)</td>
<td>10.4 (1.2)</td>
<td>10.0 (1.3)</td>
<td>9.0 (1.2)</td>
<td>1.6 (0.1)</td>
<td>6.1 (0.4)</td>
<td>4.3 (0.4)</td>
</tr>
<tr>
<td>E 200</td>
<td>11</td>
<td>5.7 (0.7)</td>
<td>8.7 (0.8)</td>
<td>8.4 (0.8)</td>
<td>7.4 (0.9)</td>
<td>1.6 (0.1)</td>
<td>6.4 (0.2)</td>
<td>4.7 (0.2)</td>
</tr>
<tr>
<td>E 400</td>
<td>10</td>
<td>4.9 (0.6)</td>
<td>10.5 (0.9)</td>
<td>9.9 (0.8)</td>
<td>8.6 (0.6)</td>
<td>1.4 (0.1)</td>
<td>5.8 (0.4)</td>
<td>4.3 (0.4)</td>
</tr>
<tr>
<td>E+C</td>
<td>9</td>
<td>5.4 (0.9)</td>
<td>8.0 (0.8)</td>
<td>7.4 (0.8)</td>
<td>7.1 (0.9)</td>
<td>1.5 (0.1)</td>
<td>6.7 (0.4)</td>
<td>5.2 (0.3)</td>
</tr>
<tr>
<td>Significance</td>
<td>NS</td>
<td>NS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

n= No. of litters; NS= Not significant (P > 0.05). Values in parentheses are standard errors of the mean.
LW= Live weight, LWG= Live weight gain.
Values in parentheses are standard errors of the mean (S.E.M.).
Control= commercial diet containing 36 mg/kg feed of vitamin E + 0 g of vitamin C; C 1= Control + Vitamin C (1 g/day); C 10= Control + Vitamin C (10 g/day); E 200= Control + Vitamin E (200 mg/kg feed); E 400= Control + Vitamin E (400 mg/kg feed); (E+C)= Control + Vitamin E (200 mg/kg feed) + Vitamin C (1 g/day).
D-F+0= day of farrowing, D-F+21= 21 days after farrowing.
serum was significantly higher \( (P<0.001) \) in those groups supplemented with vitamin E compared with the control group and the groups supplemented with vitamin C alone. On day 103 of pregnancy and at weaning, blood content of vitamin E was significantly higher \( (P<0.001) \) in groups E400 and E + C than in group E200 (Table 3). Vitamin C concentration in sow serum increased throughout gestation in all treatments but did not show a consistent relationship to dietary vitamin C intake (Table 4).

Table 3

<table>
<thead>
<tr>
<th>Treatments</th>
<th>D-0</th>
<th>D-60</th>
<th>D-103</th>
<th>D-F+21</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>1.1b (0.09)</td>
<td>1.0c (0.26)</td>
<td>1.1b (0.25)</td>
<td>1.3a (0.29)</td>
</tr>
<tr>
<td>C 1</td>
<td>1.0b (0.04)</td>
<td>1.2a (0.24)</td>
<td>1.0b (0.22)</td>
<td>1.0b (0.24)</td>
</tr>
<tr>
<td>C 10</td>
<td>1.1bc (0.06)</td>
<td>0.9b (0.29)</td>
<td>1.0b (0.27)</td>
<td>1.2a (0.29)</td>
</tr>
<tr>
<td>E 200</td>
<td>1.2bc (0.17)</td>
<td>3.6b (0.26)</td>
<td>2.6a (0.25)</td>
<td>2.5a (0.26)</td>
</tr>
<tr>
<td>E 400</td>
<td>1.1bc (0.12)</td>
<td>3.9b (0.23)</td>
<td>4.1b (0.23)</td>
<td>3.6b (0.23)</td>
</tr>
<tr>
<td>E+C</td>
<td>1.8b (0.38)</td>
<td>3.6b (0.26)</td>
<td>3.7b (0.24)</td>
<td>3.6b (0.26)</td>
</tr>
</tbody>
</table>

\( P \) value: \* \* \*** \***

Mean values within a column with different superscripts are significantly different.

\* \( P<0.05 \); \** \( P<0.01 \); \*** \( P<0.001 \).

Values in parentheses are standard errors of the mean (S.E.M.).

Control= commercial diet containing 36 mg/kg feed of vitamin E + 0 g of vitamin C; C 1= Control+ Vitamin C (1 g/day); C 10= Control+ Vitamin C (10 g/day); E 200= Control+ Vitamin E (200 mg/kg feed); E 400= Control+ Vitamin E (400 mg/kg feed); (E+C)= Control+ Vitamin E (200 mg/kg feed)+ Vitamin C (1 g/day).

D-0, D-60 and D-103= day of gestation, D-F+21= 21 days after farrowing.

4.3. Vitamins E and C in colostrum and milk

The concentration of vitamin E in colostrum was between 3.5- and 4.3-fold higher than milk. Supple-
mentation of sows with vitamin E caused a significant increase (P<0.01) in colostrum and milk vitamin E content (Table 5). In both secretions the effect of supplementation was to increase the vitamin E content 2–3-fold above that found in samples from sows not supplemented with the vitamin E. Although supplementation with 400 mg of vitamin E/kg feed increased colostrum and milk vitamin E concentration compared to that in colostrum and milk from sows given a supplement of 200 mg of vitamin E/kg feed (alone or combined with vitamin C), this increase was only significant in milk. The vitamin C content of colostrum was approximately two-fold that in milk obtained 21 days after farrowing and was significantly increased (P<0.01) by supplementation with vitamin C alone but not in a dose dependent manner. The effects of supplementation did not carry through to milk vitamin C concentrations which were similar for all treatment groups.

4.4. Vitamin E in placenta

Vitamin E concentration in placenta ranged from 0.08 to 0.22 µg/g (Table 6) and was significantly higher in sows supplemented with 400 mg of vitamin E (E 400) and those given the combined vitamin E+C compared with the control group and groups supplemented with vitamin C alone. There were no significant differences between vitamin E supplemented groups.

4.5. Vitamins E and C in piglet serum

At birth, vitamin E concentrations in piglet serum ranged from 0.32 to 0.48 µg/ml (Table 6). The concentrations of vitamin E were significantly higher in piglets from sows given treatments E+C, E400 and E200 compared to those from sows given other treatments. The vitamin E content in piglet serum at birth was significantly positively correlated with the vitamin E content in placenta (r=0.39, P<0.05) and sow serum on day 103 (r=0.52, P<0.01). Vitamin C concentrations in piglet serum were noticeably higher than that in sow on d-103 and were significantly higher in piglets from sows given treatments C 10 and E+C compared to those from sows given the other treatments. As an indicator of placental transfer the concentrations of vitamins E and C in piglet serum at birth were divided by their respective concentrations in sow serum on day 103. This is called the placental transfer ratio (PTR). It is clear from the values presented that transfer of vitamin E (Table 6) becomes less efficient as its concentration in sow serum (Table 3) increases, whereas there is no clear relationship between the transfer of vitamin C and sow serum vitamin C concentrations.

5. Discussion

5.1. Reproductive performance

Reproductive performance parameters were not significantly affected of treatment, however, sow numbers per treatment were small in this study. In studies using larger numbers of sows, Malm et al. (1976), Mahan (1994) and Mahan et al. (2000) reported that reproductive performance as measured by litter size, number live on day 0, and on day 21 and piglet weight at birth and at weaning was not affected by supplementation with 100 or 22, 44 and 66 IU vitamin E/kg diet, respectively. In contrast, Migdal and Kaczmarczyk (1993) reported that piglet weight at birth and weaning and number of piglets live on day

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Placenta (µg/g)</th>
<th>Piglet cord blood serum (µg/ml)</th>
<th>PTR ¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>0.11c (0.010)</td>
<td>0.35c (0.015)</td>
<td>0.32c (0.042)</td>
</tr>
<tr>
<td>C 1</td>
<td>0.08c (0.004)</td>
<td>0.32c (0.022)</td>
<td>0.32c (0.047)</td>
</tr>
<tr>
<td>C 10</td>
<td>0.09c (0.006)</td>
<td>0.35c (0.020)</td>
<td>0.35c (0.047)</td>
</tr>
<tr>
<td>E 200</td>
<td>0.16bc (0.026)</td>
<td>0.42b (0.020)</td>
<td>0.16c (0.047)</td>
</tr>
<tr>
<td>E 400</td>
<td>0.22b (0.030)</td>
<td>0.42b (0.016)</td>
<td>0.10b (0.042)</td>
</tr>
<tr>
<td>E+C</td>
<td>0.21b (0.057)</td>
<td>0.48b (0.017)</td>
<td>0.12b (0.042)</td>
</tr>
<tr>
<td>P value</td>
<td>*</td>
<td>**</td>
<td>***</td>
</tr>
</tbody>
</table>

Mean values within a column with different superscripts are significantly different.
*P<0.05; **P<0.01; ***P<0.001.
Values in parentheses are standard errors of the mean (S.E.M.).
Control=commercial diet containing 36 mg/kg feed of vitamin E + 0 g of vitamin C; C 1 = Control + Vitamin C (1 g/day); C 10 = Control + Vitamin C (10 g/day); E 200 = Control + Vitamin E (200 mg/kg feed); E 400 = Control + Vitamin E (400 mg/kg feed); (E+C) = Control + Vitamin E (200 mg/kg feed) + Vitamin C (1 g/day).
¹ PTR Vitamin E concentration in piglet at birth divided by vitamin E concentration in sow serum on day 103 serum.
21 were higher in groups of sows supplemented with DL-α-tocopherol and Se via intramuscular injection 21 days and 7 days before farrowing compared with a control group, although no effect was reported on litter size. However, Mavromatis et al. (1999) who used 12 sows per treatment group reported an increase in litter size, number of piglets on d-21 and piglet weight at birth and at weaning after supplementation with vitamin E (50 mg/kg of feed) and Se injections (30 mg) on days 30, 60, and 90 of gestation in sows. Mavromatis et al. (1999) also showed that selenium injection alone was less effective than when given in combination with vitamin E. Overall data suggest that vitamin E supplementation only improved reproductive performance when given in combination with selenium.

Previous studies in which large groups of sows were supplemented with vitamin C for 1 week before farrowing (Yen and Pond, 1983; Chavez, 1983; Lynch and O’Grady, 1981) found no effect of supplementation with 1 g/day, 2 g/day or 10 g/day of vitamin C on the litter size and number of still born and piglet weight at birth. In contrast, Carmona-Garcia (1983) reported that supplementation with 1 g/day of vitamin C from the beginning of gestation until weaning increased litter size at birth to 10.1 compared to 9.0 for a non-supplemented control group. This work is more comparable with the present study because the duration of the supplementation was similar, however differences in environmental and management conditions and the relatively small number of animals allocated to treatments reported here could explain the differences in response.

5.2. Vitamins E and C in sows

Increasing dietary α-tocopherol levels resulted in a clear increase in vitamin E concentration in sow serum in proportion to the dietary level of vitamin E given to the animals. It is clear that supplementation greatly increased the transfer of vitamin E to colostrum in this study (Table 5) but this was not reflected in a post-farrowing decrease in sow serum vitamin E concentration. Previous studies in sows supplemented with 22, 44, 88 IU or 50 IU or 100 IU vitamin E (Hidiroglo et al., 1993; Loudenslager et al., 1986; Malm et al., 1976) suggested that a decrease in post-farrowing sow plasma vitamin E concentration may be the consequence of a considerable partitioning of vitamin E into colostrum. In this study the high level of dietary supplementation used may have buffered the sow serum concentrations against the effects of partitioning of vitamin E to colostrum. Some interaction between vitamin C and vitamin E may be indicated by the levels of vitamin E in serum from sows given treatment E+C which was similar to that in sows given treatment E400 on days 103 and F+21 and significantly higher than in sows given 200 mg of vitamin E alone. This suggests that vitamin C may have protected vitamin E from oxidation or enhanced its regeneration (Moser and Bendich, 1991).

The inconsistency in the relationship between serum vitamin C concentration and dietary levels of vitamin C (Table 4) agrees with other studies (Chavez, 1983; Wegger and Palludan, 1984). Although on day 103, serum concentrations in sows given vitamin C alone were significantly higher than in those given the control diet, the highest values were observed in sows given treatment C 1. This is similar to values reported in sows given 1 g vitamin C per day for 7 days prior to farrowing (Chavez, 1983).

5.3. Colostrum and milk

Vitamin E in sow colostrum and milk increased with extra dietary vitamin E but the response was not linear and the efficiency of transfer to colostrum and milk appeared to decline as dietary level increased. This is supported by the fact that there was no correlation between the sow serum vitamin E content on d-103 and colostrum and milk vitamin E content. The significantly higher ($P<0.001$) level of vitamin E in colostrum than in milk was similar to that reported by Malm et al. (1976), Loudenslager et al. (1986), Hidiroglo et al. (1993), Mahan (1991, 1994) and Mahan et al. (2000).

5.4. Vitamin E in placenta

The vitamin E levels in placenta given in Table 6 cannot be compared with the literature because this is the first study to report values for vitamin E in porcine placenta. In fact, there is very little information on the vitamin E concentration in placental tissue from any species. Poranen et al. (1996) reported values for vitamin E in human placenta of 3 μM. The higher
vitamin E concentrations in placenta in groups E 400 and E+C compared with unsupplemented groups demonstrate that dietary vitamin E intake can result in small but significant increases in the vitamin E concentration in the placenta.

5.5. Vitamins E and C in piglet serum

Comparison of sow and piglet serum vitamin E concentrations and the PTR shows that the placenta acts as a barrier to vitamin E transfer. Lauridsen et al. (2002) used deuterated tocopheryl acetate to demonstrate low rates of placental transfer of vitamin E. The PTR decreased linearly with respect to dietary vitamin E intake. A decrease in the PTR reflects the fact that as vitamin E concentrations in sow serum increase a smaller proportion of this vitamin is transferred across the placenta. Malm et al. (1976) reported that transfer of vitamin E across the placenta was more efficient when no vitamin E supplement was given to gilts. More recently Mahan and Vallet (1997) suggested that net placental transfer of vitamin E was low and Hidiroglou et al. (1993) reported little influence of dietary vitamin E on serum vitamin E concentrations in newborn piglets.

The mechanism by which vitamin E is transferred via placenta is still not clear. The identification of tocopherol binding protein (TBP) in human and mice placenta (Gordon et al., 1996; Kou-ichi et al., 2001) and the reports that in humans vitamin E crosses the placenta bound to a placental tocopherol binding protein (Accuff et al., 1998) have led to a speculation that a similar process occurs in pigs. If this is true, these proteins may become saturated if exposed to high α-tocopherol concentrations on the maternal side of the placenta. This could account for the decrease in efficiency of transfer of α-tocopherol as sow serum levels increased. Further work is required to clearly define the mechanism by which the vitamin E is transferred across the placenta.

Comparison of the sow and piglet plasma vitamin C concentrations shows that vitamin C may cross the placenta and indeed, the placenta may be important in concentrating vitamin C in the piglet blood. The mechanisms for transport of vitamin C are not clear. Choi and Rose (1989) demonstrated that in human placenta uptake of dehydroascorbic acid is much higher than that of ascorbic acid and in the near term placenta dehydroascorbic acid is three to six times more readily taken up than ascorbic acid and is subsequently converted back to ascorbic acid by the foetus (James and Stephenson, 1998). This mechanism may also occur in pigs and could explain the apparent concentration of vitamin C in the piglet.

6. Conclusion

Sow reproductive performance and piglet performance to weaning were not affected by supplementation with vitamin E and vitamin C. There was little placental transfer of vitamin E. Placental vitamin E concentrations were low but were increased with dietary vitamin E supplementation. With increasing dietary vitamin E the efficiency of placental transfer decreased. Colostrum and milk were the main supply of vitamin E to the newborn piglet. Vitamin C supplementation had small but significant effects on sow plasma and milk concentrations and was markedly increased in piglet cord blood compared to that in sows nearing parturition.

Acknowledgments

The authors thank Hernán Celaya, Erika Javier and Michael Birnie for their technical assistance and Dr. Gustavo Córdova S., owner of the Granja Sta. Bruna. This study was supported by Hoffman-La Roche Ltd. Basle, Switzerland. Araceli Pinelli-Saavedra was a recipient of a research scholarship from CONACyT.

References


pheryl acetate effects on placental and mammary vitamin transfer in sheep. J. Anim. Sci. 72, 1636 – 1640.