PRACTICAL EXPERIENCES WITH L-CARNITINE

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1. Introduction

HARMEYER (1997) was the first to report in detail on the physiological role of L-carnitine and the effects of carnitine deficiency and supplementation in domestic animals in this series of conferences. NELSSEN (1999) used the same platform to present several studies conducted at Kansas State University confirming positive effects of L-carnitine on the reproductive performance of breeding sows. Based on these research results, L-carnitine is already widely used in sow nutrition in America where some 800,000 sows (about 10 % of the total population) are fed diets supplemented with L-carnitine (OWEN, 2001).

In recent years Europe has also seen a steady increase in the popularity of L-carnitine. This rapid development was driven by a continuous accumulation of new experiences in the use of L-carnitine in livestock nutrition. An extensive body of knowledge about the effects and mode of action of L-carnitine has been built up in collaboration with various scientific institutes in Germany and abroad. The main focus of this work has been the effect on reproductive processes in breeding sows (EDER et al., 2001; WEBER et al., 2000). The European research largely confirmed the results of American studies - despite differences in management and feeding conditions.

Since then the first results of trials on commercial farms have become available. These are presented below, together with a brief review of the current major applications of L-carnitine in animal nutrition.

2. Applications of L-carnitine

2.1 Functions of L-carnitine

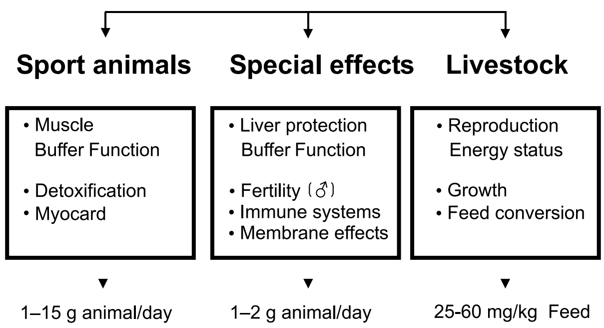
Recent research has produced mounting evidence and experimental data showing that L-carnitine, as well as promoting the mitochondrial burning of fatty acids (BÖHLES et al., 1983; OWEN et al., 1996), can also perform other biochemical functions. These include its function as acetyl buffer, the maintenance of sufficiently high coenzyme-A concentrations in the mitochondria under conditions of anaerobic energy generation, kick-starting the tricarboxylic acid cycle and stimulating ATP transport from the mitochondria during intensive muscle activity.

The specific functions and the physiological role of L-carnitine in the metabolism are not considered in detail in this article because the essential catalytic and metabolic function of L-carnitine in the intermediate metabolism of livestock has already been fully described elsewhere (HARMEYER, 1997). For ease of classification and in view of the practical benefits of L-carnitine in the feeding of livestock the major current applications are presented below (Fig. 1). They are partly species-specific and describe different metabolic functions of L-carnitine.

2.2 Mode of action of L-carnitine

In situations where the effective provision of energy is essential for high performance or the maintenance of animal health, L-carnitine is of special significance because of its key function in the energy metabolism (SILIPRANDI et al., 1994; Di LISA et al., 1995; SCHOLTE et al.,1996). L-carnitine as co-factor catalyzes the passage of activated fatty acids across the mitochondrial membrane. The transport of activated fatty acids of medium and long chain

Figure 1: Applications



length through the inner mitochondrial membrane to the site of fatty acid combustion is only possible with the aid of L-carnitine. L-carnitine is also crucial in situations of defective fatty acid metabolism, when it acts as a buffer substance for energy-rich intermediates.

Metabolic situations where the need for L-carnitine is increased are found in very young animals with limited endogenous carnitine synthesis (BORUM, 1986). They also occur in high-performing and/or reproducing animals, who are known to have a very high energy requirement.

2.3 Sporting animals

For L-carnitine to perform its function as an acyl store in working muscle or in the liver requires a relatively high daily intake with the diet. As for top athletes, the recommended allowance is therefore in the region of several grams per animal and day.

In hard-working animals such as sporting horses daily supplements of 10 to 15 g L-carnitine achieve the required levels of L-carnitine in plasma and muscle tissue. L-carnitine occurs in muscle in molar concentrations, whereas the concentrations of the remaining intermediates involved in the energy metabolism are in the micromolar range (HARMEYER, 1997). High plasma concentrations give L-carnitine the ability to act as a store of acetyl-CoA and to react in a stoechiometric ratio with this energy-rich substrate. This ability can be utilised to prevent an accumulation of toxic concentrations of acyl-CoA during physical activity. Also of significance is the L-carnitine-dependent modification of the ratio of free to bound CoA in the mitochondria. By binding acetyl groups, L-carnitine can reduce the production of acetyl-CoA which results from the breakdown of pyruvate to acetate, thus preventing depletion of the CoA reserves. In this way L-carnitine reduces the conversion of pyruvate to lactic acid and counteracts premature fatigue. The acetylcarnitine formed under these circumstances is once more available as a reservoir of “active acetate” for energy production, for example during the warm-up and the recovery phase.

2.4 Special effects

The buffering activity of L-carnitine is also of benefit in situations of increased lipolysis as for example during the perinatal period in dairy cows when more fat deposits are mobilised to meet the increased energy requirement for the impending milk production. In this type of metabolic situation it is not on the muscles but the liver which dominates the proceedings. The acetyl group of acetyl-CoA, which is abundantly produced from lipolysis and breakdown of fatty acids, is increasingly transferred to L-carnitine as required. The resulting acetylcarnitine can be passed by the liver to the blood.

Trials have shown that supplemental L-carnitine increases hepatic ketogenesis while at the same time stimulating the burning of ketone bodies by peripheral tissues. This was associated with a decline in the concentration of ketone bodies in plasma. Further trials are needed to find out whether the ketogenic states developing in these animals can be prevented by L-carnitine supplementation, with consequent beneficial effects on performance.

2.5 Reproduction

The effect of L-carnitine supplementation on the reproductive performance of breeding animals has been intensively researched in the past three years. We know that the vitality and fertility of high-producing livestock animals is dependent on an adequate supply of all necessary macro- and micronutrients. The most important item for reproducing animals is energy, which must be supplied in amounts appropriate to the individual's physiological status. The close correlation between reproductive performance and nutritional status is well known, especially in the case of high-producing breeding sows.

The key requirement for dietary management with a view to successful piglet production is to stabilise sow fertility at a high level without reducing the sows' longevity.

Current scientific studies have demonstrated beneficial effects of L-carnitine supplementation at 50 mg per kg feed on the reproductive performance of breeding sows (FREMAUT, 1993; MUSSER et al., 1996; EDER et al., 2001). These authors associate the improvement in the reproductive performance of the breeding sows with the key role of L-carnitine in the energy metabolism. The supply of L-carnitine is therefore of crucial importance in intensive livestock production.

3. Natural concentrations of L-carnitine in feeding stuffs

L-carnitine is essential to life in humans and animals. It can be manufactured by the body itself (mainly in the liver). With the exception of very young animals the demand for L-carnitine in healthy animals with moderate performance is therefore covered by endogenous synthesis and native concentrations in feed components ingested with the diet (Table 1). Ration components of animal origin are considered good natural sources of L-carnitine.

Meat meals and fish meals for example supply up to 150 mg L-carnitine per kg. Plant-derived feed components on the other hand, such as cereals and their by-products and by-products of oil production, have relatively low concentrations ranging from 5 to a maximum of 20 mg L-carnitine per kg of original substance. In addition to the concentrations shown in Table 1, reliable data are available for a wide range of other conventional feed components for calculating the natural L-carnitine concentrations in compound feed (HARMEYER, 1998).

As a consequence of the feeding ban issued in November 2000 on a number of the L-carnitine rich materials of animal origin listed here, we can expect typical rations to have distinctly lower L-carnitine concentrations from now on. Previously, complete feeds for pigs and poultry would normally have contained 5 to 7 % meat and bone meals,

Table 1: L-carnitine: Typical contents in feedstuffs (mg/kg)

Feedstuff plant origin			
Corn	5	Soybean meal	20
Barley	10	Rapeseed	10
Wheat	5	Sunflowers	10
Wheat bran	15	Cottonseed	5
Oats	5		
Feedstuff animal origin			
Animal meal	150	Meat bone meal	80
Fish meal	120	Plasmaprotein	15
Feather meal	10	Blood meal	10

rising to 40 % in the case of protein concentrates. Leaving out these components reduces the L-carnitine content of complete sow feeds by almost half.

Taking a commercial diet for pregnant and nursing sows as an example, we calculated the L-carnitine content in the final ration (Table 2). On the assumption that a ration for pregnant sows contains 3 % fish meal and a ration for nursing sows 5 %, the calculated content of L-carnitine from the components used is 11 mg or 15 mg per kg of complete feed. If the ration is formulated solely with plant-derived components the content of native L-carnitine is distinctly lower, namely between 9 and 10 mg per kg feed.

Table 2: Diets for sows with and without fish meal addition (in %)

	Sows gestation diet		Sows lactation diet	
Wheat		10,0	30.0	35.0
Barley	47.5	50.0	48.3	35.0
Triticale	20.0			
Mineralfeed	2.5	2.0	3.7	3.0
Soybean meal	5.0		18.0	10.0
Fish meal		**3.0**		**5.0**
Rapeseed		5.0		
Alfalfa	15.0	10.0		
Wheat bran	10.0			10.0
Sugarbeet dehy.		20.0		
Soybean oil				2.0
ME, MJ/kg	11.4	11.0	12.8	12.7
Crude protein %	14.1	13.3	17.1	16.8
L-carnitine, mg/kg	9.0	11.0	10.0	15.0

Based on the results of scientific studies, the general consensus is that at least 50 mg L-carnitine per kg feed is needed to ensure an optimal supply of sows. In these trials adding 50 mg L-carnitine per kg feed to the diet during pregnancy and lactation led to a marked improvement in the reproductive performance of the breeding sows. The difference of 30 to 40 mg per kg (depending on the composition of the ration) can only be made up by dietary L-carnitine supplementation.

4. Field studies

4.1 Liveweight development of sows

Studies were conducted in collaboration with major piglet producers in Germany, France and Austria to investigate whether endogenous synthesis and the low dietary supply of L-carnitine is sufficient for high performance requirements under commercial conditions or whether the productivity of breeding sows in critical phases can be markedly improved by selective supplementation with L-carnitine.

In each of these field studies (Table 3) about 120 animals were monitored over one reproductive cycle and included in the evaluation. The duration of the suckling period differed slightly on each farm, but was within the conventional range of 20 to 28 days on all participating farms.

Table 3: Impact of L-carnitine (50 ppm) on body mass development of sows (Testimonials 2000 and 2001)

N° sows Suckling period	L-carnitine mg/kg	Body mass, kg Mating (M)	Weaning (W)	Difference, kg Δ W-M	
125 sows* 28 d	0 50	279 280	230 235	-49 -45	-4
106 sows 21 d	0 50	260 255	218 212	-42 -43	+1
120 gilts 20 d	0 50	194 199	175 187	-19 -12	-7
127 gilts 21 d	0 50	183 185	152 161	-31 -24	-7

The test animals received a supplement which ensured a daily L-carnitine intake of 125 mg during pregnancy and 250 mg during the suckling period. Where the L-carnitine supplement was supplied via a commercial diet, L-carnitine was added at a dose of 50 mg per kg feed, assuming normal feed intakes.

The changes in the sows' liveweight were monitored by individual weighings at mating and at the end of the suckling period. In the field trial marked with an asterisk the body mass loss of the breeding sows during the suckling period was determined.

As was to be expected, marked body mass losses were observed in the breeding sows studied, which differed in magnitude in the various trials. The sows supplied with L-carnitine lost up to 7 kg less body mass between mating and weaning of the piglets. On two farms the effect of L-carnitine supplementation on lactation-induced body mass losses among gilts was conspicuous.

This observation is in close agreement with the results of studies by MUSSER et al. (1997), WEBER et al. (2000) and EDER et al. (2001). Their findings also suggest that gilts in particular respond more strongly to L-carnitine supplementation than sows with a higher parity.

Gilts are known to have a higher energy requirement during the first two reproductive cycles because their growth is not yet completed. A more efficient energy supply through L-carnitine supplementation might provide an explanation for the observed positive effects on body mass development of primiparous sows.

Future studies are needed to find out whether the positive effect of L-carnitine supplementation on body condition of breeding sows may also influence fertility and longevity in the long term.

4.2 Body mass development of suckling pigs

Along with good maternal body condition, the body mass development of the offspring is also crucial for the success of piglet production. It should be noted that the effects on piglet performance described below are solely due to the treatment of the sows as the suckling pigs themselves did not receive any L-carnitine supplements in these trials. The weights of the piglets at birth and at weaning are indicated in kg. The performance of the control animals was set at 100 % and treatment-related differences are shown in per cent relative to the control (Table 4).

Table 4: Impact of L-carnitine (50 ppm) on body mass development of nursery piglets (Testimonials 2000 and 2001)

N° sows Suckling period	L-carnitine mg/kg	Body mass of piglets, kg Birth	relative	Weaning	relative
125 sows 28 d	0 50	1.46 1.51	100 103	7.6 8.0	100 105
106 sows 21 d	0 50	1.34 1.53	100 114	6.9 7.3	100 106
120 gilts 20 d	0 50	1.40 1.30	100 93	5.3 5.5	100 104
189 sows 28 d	0 50	1.43 1.46	100 102	8.3 8.5	100 102

The birth weight of the piglets from the L-carnitine supplemented sows was 2 to 14 % higher than that of the control group. These findings are also in accord with the results of studies by MUSSER et al. (1997) and EDER et al. (2001). There the increase in body mass at birth was up to 100 g per piglet.

This is obviously of considerable economic interest as well, in view of the correlation between birth weight, piglet survival rate and growth intensity during the subsequent life stages. The fact that piglets from sow groups supplemented with L-carnitine achieved up to 6 % higher weaning weights confirms what has been said above.

The effect of L-carnitine supplementation on litter body mass becomes even more evident at weaning (Table 5). The body mass of the litter increased by amounts ranging from 3 to 7 % compared with the control litters, while the number of weaned piglets was either slightly improved or equal. High weaning weights are desirable because they are associated with faster growth during the rearing phase and the subsequent finishing period. Further trials are needed to investigate whether the effect of supplemental L-carnitine in sow diets might also promote more homogeneous weight distribution of piglets within a litter, a high priority for fatteners.

4.3 Number of born and weaned piglets

The number of saleable end products is of crucial importance to the piglet producer for obvious commercial reasons. The relevant parameters, i.e. the number of born and weaned piglets, were also improved in the field trials described here (Table 6). The number of piglets born to sows supplemented with L-carnitine increased by up to 8 %. This, combined with lower piglet losses during the suckling period in many cases, led to an increase in the

Table 5: Impact of L-carnitine (50 ppm) on littersize and littermass at weaning (Testimonials 2000 and 2001)

N° sows Suckling period	L-carnitine mg/kg	Piglets/litter	Littermass kg	relative
125 sows 28 d	0 50	9.4 9.4	70.8 75.5	100 107
106 sows 21 d	0 50	10.4 10.6	76.7 79.1	100 103
120 gilts 20 d	0 50	9.1 9.2	48.1 50.5	100 105
189 sows 28 d	0 50	9.9 10.2	82.0 87.3	100 107

number of weaned piglets in the region of 1 to 3 %. This is equivalent to an extra 0.1 to 0.3 weaned piglets per sow and litter. If we apply this value to calculate the reproductive performance of a breeding sow over a year, we can expect an additional 0.3 to 0.7 weaned piglets as a result of L-carnitine supplementation.

Table 6: Impact of L-carnitine (50 ppm) on piglets born and weaned (Testimonials 2000 and 2001)

N° sows Suckling period	L-carnitine mg/kg	No piglets Birth	relative	Weaning	relative
125 sows 28 d	0 50	11.8 11.9	100 101	9.3 9.4	100 101
106 sows 21 d	0 50	11.4 12.1	100 106	10.4 10.6	100 102
120 gilts 20 d	0 50	10.2 10.0	100 98	9.1 9.2	100 101
189 sows 28 d	0 50	11.1 12.0	100 108	9.9 10.2	100 103

When evaluating the results presented here it is important to bear in mind that all trials were conducted under practical conditions. We cannot apply the same strict scientific standards as are used in institute trials. A statistical analysis of the results is therefore difficult and the statistical significance of effects is rarely proved. In view of the consistency of the results in all the field studies conducted, which correlate well with observations of scientific studies, both directionally and in terms of magnitude, it would seem entirely justified to attribute the observed effects to the L-carnitine supplement of 50 mg per kg feed.

5. Conclusion

The beneficial effect of L-carnitine supplementation at 50 mg per kg feed during pregnancy and lactation was reproduced in extensive field trials. The reproductive performance of breeding sows was substantially improved. This statement is essentially based on key parameters such as body condition and fitness of the sows and number, vitality and liveweight development of the piglets. The observation that the effects of L-carnitine supplementation on weight development and reproductive performance were more marked in gilts is indicative of an increased energy requirement at this critical stage of life.

As regards the mode of action of L-carnitine, the observed effects do not allow a definite conclusion to be drawn at this time. The functions of L-carnitine in the fatty acid metabolism do not by themselves provide an adequate explanation for these effects. EDER et al. (2001) assume that L-carnitine has a positive effect on the fetal nutrient supply. Other authors postulate a connection between the maternal L-carnitine supply during pregnancy and the stimulation of endogenous growth hormones such as insulin and IGF I. The latter have been associated with increased muscle fibre formation in the fetus (MUSSER et al., 1999). These and other hypotheses are currently being studied by several research teams.

6. Literature

BÖHLES, H, H. SEGERER, W. FEKL, K. STEHR (1983): Tierexperimentelle Untersuchungen über Veränderungen des Lipid- und Proteinstoffwechsels bei L-Carnitin-supplementierter totaler parenteraler Ernährung. Infusionsther. 10, 24-31

BORUM, P.R., S.G. BENNETT (1986): Carnitine as an essential nutrient. J. Am. Coll. Nutr. 5, 177-82

Di LISA, F., R. BARBATO, R. MENABO, N. SILIPRANDI (1995): Carnitine and carnitine esters in mitochondrial metabolism and function. Dev. Cardiovasc. Med. 162, 21-38.609

EDER, K., A. RAMANAU, H. KLUGE (2001): Effect of L-carnitine supplementation on performance parameters in gilts and sows. J. Anim. Physiol. a. Anim. Nutr. 85, 73-80

FREMAUT, D.J., G. De RAEYMAECKER, J. LATRÉ, J.V. AERTS (1993): Hebben lakterende zeugen een tekort aan L-carnitine?. Varkensbedrijf 3(6), 20-23

HARMEYER J., C. SCHLUMBORN (1997): Die physiologische Bedeutung von L-Carnitin und Effekte von Carnitinzulagen bei Haustieren. Proc 6th Symp Vitamine und weitere Zusatzstoffe bei Mensch und Tier, 24.-25. Sept., Friedrich Schiller University, Jena (Germany): in Druck

HARMEYER, J. (1997): Die physiologische Rolle von L-Carnitin, Auswirkungen von Mangel und Zulagen bei Haustieren, Lohmann Symposium

HARMEYER, J., C. SCHLUMBOHM, M. BAUAMGARTNER (1998): Der Gehalt an L-Carnitine in Futter- und Lebensmitteln pflanzlicher und tierischer Herkunft und der Einfluss von Herstellungsverfahren auf dessen Gehalt. In: Einfluss von Erzeugung und Verarbeitung auf die Qualität landwirtschaftlicher Produkte, published by Ed VDLUFA, Darmstadt, 489-92

MUSSER, R.E., R.D. GOODBAND, K.Q. OWEN, M.D. TOKACH, J.L. NELSSEN, S.A. BLUM, C.A. CIVIS (1996): Effects of L-carnitine on gestating and lactating sow performance. Res. report (not published)

MUSSER, R.E., R.D. GOODBAND, M.D. TOKACH, K.Q. OWEN, J.L. NELSSEN, S.A. BLUM, S.S. DRITZ, C.A. CIVIS (1997): Effects of L-Carnitine fed during gestation and lactation on sow and litter performance. Swine Day (Kansas State University), 52-79

MUSSER, R.E. (1999): Additional L-Carnitine in the gestating sow diet improves carcass characteristics of the offspring. Swine Day (Kansas State University), 37-40

NELSSEN, J.L. (1999): New Developments in Sow Nutrition in the USA, Lohmann Symposium

OWEN, K.Q., H. JI, C.V. MAXWELL, J.L. NELSSEN, R.D. GOODBAND, M.D. TOKACH, G.C. TREMBLAY, S.I. KOO, S.A. BLUM (1996): Effect of dietary L-carnitine on growth, carcass characteristics, and metabolism of swine. Swine Day (Kansas State University), 103-110

OWEN, K.Q. (2001): Sows and their offspring perform better when sow diets are supplemented with Carniking. Lohmann Symposium, The Netherlands

SCHOLTE, H.R., A.M.C. BOONMAN, L.M. HUSSAARTS-ODIJK, J.D. ROSS, L.J. Van OUDHEUSDEN, R.P. PEREIRA, H.C.S. WALLENBURG (1996): New aspects of the biochemical regulation of the carnitine system and mitochondrial fatty acid oxidation. In: Carnitine - Pathochemical Basics and Clinical Applications. Eds Seim H, Löster H, Ponte Press Bochum, 11-31

SILIPRANDI, N., R. VENERANDO, V. TASSANI (1994): The "carnitine system": recent aspects. Adv. Exp. Med. Biol. 368, 161-4

WEBER, M., P. STENZEL, S. JACOBS (2000): Untersuchungen zur Wirksamkeit von L-Carnitin auf die Leistung von Sauen. 6. Tagung Schweine- und Geflügelernährung, Nov. 2000 Lutherstadt Wittenberg