L-CARNITINE: IMPORTANCE FOR PIG BREEDING

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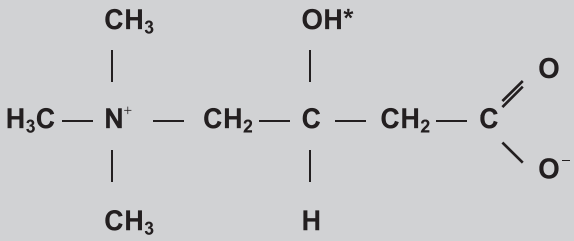
Introduction

Only in the last few years has the attention of animal nutritionists been drawn to an interesting natural compound: L-carnitine. The substance has since become firmly established in human medicine and competitive sports (Neumann, 1996). It is conceivable that L-carnitine will also develop into a valuable supplement in animal husbandry. The enormous scientific interest in the substance is reflected not at least in the fact that the literature on carnitine has grown dramatically in recent years, and now comprises over 6000 scientific publications. The following article describes some of the functions of L-carnitine that are relevant to the reproduction and breeding of piglets.

Chemical properties of L-carnitine

The vitamin-like substance L-carnitine was discovered as a natural constituent of muscle tissue at the beginning of the century. In chemical terms it is an amino acid derivative with the name β-hydroxy-γ-trimethyl-aminobutyrate (see Figure 1) with a molecular weight of 161. It thus falls within the range of the B-complex vitamins. In chemically pure form L-carnitine occurs as a white powder that is highly soluble in water. It is characterized by high thermal stability, with a melting point of over 210°C.

Figure 1: L-carnitine (β-hydroxy-γ-trimethyl-aminobutyrate)

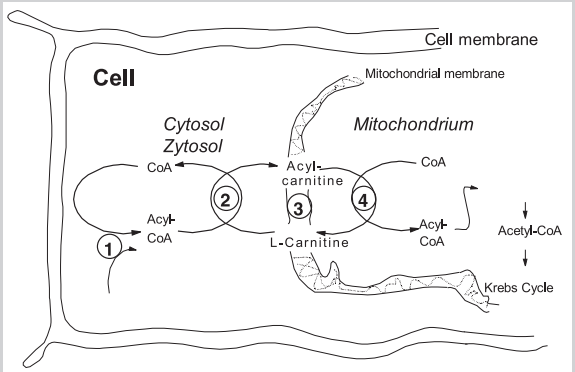


* the activated fatty acids bond at this point

Biological function

L-carnitine plays a key role in energy provision in the cells of humans and animals (Di Lisa et al., 1995; Scholte et al., 1996; Siliprandi et al., 1994). As a co-factor L-carnitine catalyses the transport of activated fatty acids through the mitochondrial membrane (see Figure 2).

Figure 2: The L-carnitine carrier system for transporting long-chain fatty acids through the mitochondrial membrane to the site of b-oxidation

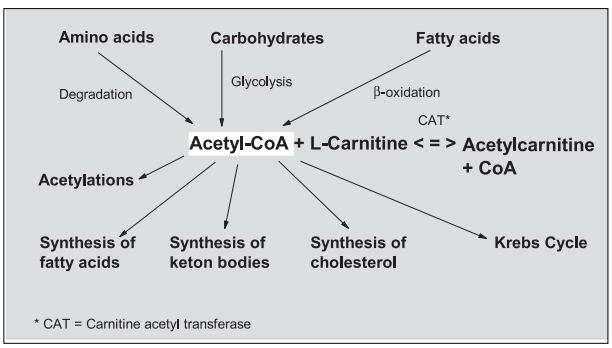


1 = Acyl-CoA synthetase 2 = Carnitine palmitoyl transferase (CPT I)
3 = Carnitine translocase 4 = Carnitine palmitoyl transferase (CPT II)

The acyl-CoA-synthetase activates fatty acids to produce acyl-CoA. Finally, the CPT I transfers the activated fatty acid (acyl residue) to the L-carnitine, producing acylcarnitine. The carnitine translocase transports the acylcarnitine into the mitochondria; in the opposite direction L-carnitine is transported out of the membrane. The CPT II transfers the fatty acid in turn to CoA. The fatty acid is available for energy provision.

No less important is its function as a buffer substance for the intermediate storage or transport of activated short-chain fatty acids in and out of cell organelles and cytosol (see Figure 3). This increases the availability of free CoA in the cells, which is essential for the optimal progression of metabolic processes and promotes the combustion of fatty acids (Böhles et al., 1983; Owen et al., 1996). Utilization of the energy in the feed or body stores is thus rendered more efficient.

Figure 3: Buffer function of L-carnitine: Storage of acetyl residues in the form of acetyl carnitine with simultaneous release of CoA. The enzyme CAT transfers the acetyl residue to L-carnitine.



* CAT = Carnitine acetyl transferase

L-Carnitine is involved, directly or indirectly, in numerous other biochemical processes in the body, including the synthesis and protection of cell membranes (Uhlenbruck, 1996). Leaky cell membranes reduce the water-retaining capacity, increase the energy consumed in maintaining electrochemical potentials and impair the synthesis performance of cells.

It has also been shown that L-carnitine actively promotes the development and preservation of immunocompetence (antibody formation and phagocytic activity) (Uhlenbruck, 1996) and protects nerve cells from the toxic effects of ammonia (Felipo et al., 1994).

Additionally, L-carnitine is essential for spermatogenesis and sperm motility (Jeulin et al., 1988 and 1994). Certain fertility problems correlate directly with L-carnitine levels in the epididymides and the spermatozoa. In particular, sperm motility is directly dependent on the quantity of acetylcarnitine stored in the sperm cells. The energy-rich compound acetylcarnitine serves as the primary energy source for sperm motility after insemination.

Anecdotal evidence has highlighted other pathological consequences of inadequate L-carnitine provision. Thus, L-carnitine deficiency in dogs results in a drop in plasma albumin concentrations (Neu, personal communication). Albumins are important for maintaining the osmotic pressure in blood vessels. A drop in the concentration of these proteins increases the risk of edema.

A direct ergogenic effect of L-carnitine on the myocardium has been demonstrated in humans and animals (Neumann, 1996; Neu, 1995; Neu, personal communication). These findings can doubtless be applied to pigs to a certain extent. Studies are currently investigating the extent to which L-carnitine supplementation can help reduce the incidence of the sudden death syndrome. It should also be pointed out that the functioning of erythrocytes as an oxygen supplier is related to the L-carnitine concentration.

In the context of breeding, specific mention should be made of the provision of L-carnitine to foetuses and neonates. Studies with model animals and humans have shown that the mother's levels of L-carnitine have a direct effect on the supply to the neonates (Lohninger et al., 1996). L-carnitine finds its way to the fetus via the placenta. Inter alia, L-carnitine is essential for lung maturity. Fetuses with a good L-carnitine provision have improved chances of survival in the event of premature birth (Lohninger, 1996).

After birth a fundamental change takes place in energy production in the newborn mammal. Within the uterus glucose serves as the primary energy source, whereas post partum fatty acids are oxidized, a process in which L-carnitine plays a vital role. Neonates possess very limited endogenous synthesis (Borum, 1986), which only develops during the first few weeks of life. Nature takes account of this state of affairs by ensuring that the mother's milk contains high levels of L-carnitine at the start of lactation. The colostrum of sows contains approx. 60 mg L-carnitine per litre; during the course of lactation this level drops to approx. 25 mg/l.

Significance for pigs

As has been demonstrated in trials, the above-listed functions of L-carnitine in tissues and organs have practical implications for pig breeding. The benefits of L-carnitine supplementation to boars, breeding sows and reared piglets are described below.

Boars

Boars are known to be highly sensitive animals. Particularly during the mating season boars are exposed to considerable metabolic stress. L-carnitine supplementation supports the processes of energy provision and thus helps the boars overcome this stress. Adequate L-carnitine supplementation is also thought to assist the body's immune response and thus reduce the risk of animal contracting infections.

L-carnitine also promotes spermatogenesis as regards sperm volume, sperm count and quality (Thielman, 1996, Herfen et al., 1997). Wherever cell division takes place, high energy turnover rates are observed at the cellular level. L-carnitine is also especially significant in sperm cells. Sperm cells contain very high concentrations of acetylcarnitine, a compound that provides the sperm with their first, important energy source after insemination. Sperm motility ultimately depends on this (Jeulin, 1994).

The results of a representative boar trial, conducted in conjunction with the Industriele Hogeschool CTL, Ghent, are reported below (Table 1). In this trial Dutch Landrace boars were fed a commercial boar feed. The test group received 720 mg L-carnitine per animal/day in the feed and the study lasted 118 days. The boars were deseminated 23 times in all. Artificial insemination portions were prepared from the sperm samples in accordance with standard practice.

1.6 portions more per mating could be prepared in the group with L-carnitine supplementation thanks to the increased sperm volume with only a minimally reduced sperm concentration.

Table 1: Effect of L-carnitine supplementation on the sperm production of boars (Dutch Landrace)

Parameter	Without L-carnitine (Control)	With L-carnitine (720 mg/d)	Change compared to control
Number of boars	20	20	
Duration of study (days)	118	118	
Number of matings	23	23	
Sperm volume per mating (ml)	214[a]	246[b]	14.8%
Sperm concentration (10^8/ml)	4.7	4.5	- 4.2%
Percentage of viable sperm (%)	75.6	75.3	
Number of portions per mating	19.6	21.2	1.6
Number of portions per boar	451	488	37

[a, b] Means with differing indices show statistically significant differences from each other. Source Thielman, 1996

Pregnant and lactating sows

The aim of any breeder is to maintain the fertility of the sows at a high level and to avoid compromising the reproductive life span of the breeding animals. During pregnancy the sow should be able to put on about 35 kg

in weight (foetuses plus the sow's body stores). During lactation, the sows should not lose more than 15 kg in body substance. Trial results indicate that L-carnitine supplementation can assist in this undertaking.

Finally, it should be pointed out that lactating sows secrete large amounts of L-carnitine in their milk. A high-performance sow produces about 300 litres of milk during a 4-week lactation period. With an average L-carnitine content of 30 mg/l this corresponds to an L-carnitine quantity of approx. 10 g (200 to 400 mg/day).

A correlation is known to exist between the birth weight of the piglet and its growth rate in subsequent periods of life. This growth advantage is ultimately reflected in an earlier onset of slaughter readiness. Trials have shown that L-carnitine supplementation in pregnant sows positively influences the birth weight of the piglets (Musser et al., 1997). The supplemented sows show higher plasma levels of insulin and IGF-I (Insulin-like Growth Factor I). Both growth factors play an essential role in increasing the number of muscle cells in the foetus.

As mentioned above, the sows should, if possible, lose no more than 15 kg body weight during lactation. Two strategies are available in practice to achieve this aim:

- On the one hand, L-carnitine can be administered directly to the sows. Trials have demonstrated that L-carnitine supplementation leads to an increased L-carnitine content in the milk. The suckling piglets thus receiving more L-carnitine. The sows lose less weight during lactation with consequent benefits for the following reproduction phase (Harmeyer, 1995; Harmeyer and Schlumborn, 1997).
- On the other hand, the L-carnitine can be administered directly to the piglets via prestarters. A tasty, energy-rich prestarter relieves the strain on the sows particularly during the 3rd and 4th weeks of lactation. They then break down less body substance since the piglets consume less milk. As a result, the sows again remain in a better physical condition for the next reproduction phase (Provimi, 1997).

The findings of trials with L-carnitine supplementation can be summarized as follows (Fremaut et al., 1993; Harmeyer, 1995; Harmeyer and Schlumborn, 1997; Musser et al., 1996):

- improved physical condition of the sows at the end of pregnancy (increased weight and fat stores)
- increased piglet birth weight
- faster piglet growth
- fewer piglet losses resulting from crushing during lactation
- larger litters, both in terms of number and weight, at weaning
- less weight loss of sows during lactation
- fewer unproductive days.

Orphaned suckling piglets

Orphaned suckling piglets reared on milk substitutes represent a special case. Since a sow's milk naturally contains between 25 and 60 mg L-carnitine per litre of milk, the milk substitutes for orphaned suckling piglets must contain about 500 mg L-carnitine, assuming that 1 kg of milk substitute is diluted with 8 l of water.
Aerts and Fremaut (1996) supplemented the milk substitute with 600 mg L-carnitine. The piglets in the L-carnitine group grew around 13% faster than those in the control group (Table 2). Feed utilization improved by 10%.

Table 2: Effect of L-carnitine supplementation of milk substitute on the growth, feed intake and utilization of 9-day old piglets

Parameter	Treatment		Mean
	Control group	L-carnitine group	
Number of piglets	30	30	
Initial weight (g)	3694	3718	3706
Final weight (g)	5759	6049	5901
Duration of trial (d)	17.3	17.4	17.3
Growth (g/d)	119	135	127
Dry mass intake (g/d)	156	159	158
Dry mass utilization	1.31	1.18	1.24

Source: Aerts and Fremaut (1996)

Weaners

Particularly during the first week after weaning, piglets are exposed to increased stress as a result of the changes in both housing and feed. Stress is always associated with depressed performance.

On three breeding farms in Brittany, France, the feed was supplemented with 30 mg/kg L-carnitine during the first 14 days after weaning (Pommier et al., 1997). The study involved a total of 800 weaners. The L-carnitine supplementation improved daily growth by 3% ($p = 0.03$). A trend toward a reduction in mortality was apparent (0.3% compared to 0.5% in the control group).

Various trials have shown that L-carnitine supplementation throughout the breeding phase, from weaning until a live weight of about 25 kg, can accelerate the growth of the piglets (Table 3).

Conclusions

In today's world of animal husbandry, with demands for high performance in reproduction and growth, the animal's body needs an adequate supply of L-carnitine. In many cases, endogenous synthesis is unable to meet the requirements and supplementation in the feed seems to be a useful strategy. L-carnitine supplementation helps animals overcome energy bottlenecks with minimal performance losses, particularly in conditions of stress, nutrient imbalances and the threat of illness.

As a constituent of all organisms, L-carnitine occurs naturally in varying concentrations in different feeds. Plant-based feeds generally contain very little L-carnitine, while animal-based feeds are richer in L-carnitine. Vegetable and animal fats contain no L-carnitine.

Dosage recommendations

The following dosages are recommended for the supplementation of feeds for boars, sows and piglets. Table 4 gives details of the minimum contents in the feed (natural content plus the added L-carnitine). It is therefore helpful to estimate the natural contents in the formulation in

Tabelle 3: Effects of L-carnitine supplementation of weaner feeds

Trial no.	Breed	Natural L-carnitine cont. mg/kg	L-carnitine suppl. mg/kg	Age at start of trial Weeks	Initial weight kg	Final weight kg	Growth g/d	Feed utilization
1	Landrace x LW x Piétrain	<5	0 20 40	5	9.5	24	403[a] 452[b] 418[a]	1.95[a] 1.77[b] 1.95[a]
2	Landrace x LW x Piétrain	<5	0 20 40	5	9	23	391[a] 415[b] 385[a]	189[a] 159[b] 1.64[b]
3	LW	12	0 40	5	8.6	22	456[a] 512[b]	1.41[a] 1.37[a]
4	Dalland	<5	0 25 50	4	7	22	417[a] 440[b] 452[b]	1.75[a] 1.77[a] 1.66[a]
5	Dalland	<5	0 25 50	4.5	8	23	423[a] 448[a] 451[a]	1.73[a] 166[b] 1.65[b]
6	LW	10	0 25 50	5.5	11	27	444[a] 434[a] 453[a]	1.57[a] 1.54[a] 1.48[b]

Trial numbers: 1: Piroutz, 1990 (Austria), 2: Piroutz, 1990 (Austria), 3: Pfirter, 1991 (Switzerland), 4: Daza, 1994 (Spain), 5: Daza, 1995 (Spain), 6: Jost, 1994 (Switzerland).

[a, b] Means with different letters show statistically significant differences from each other ($p < 0.05$).

advance, or else arrange for these to be determined by chemical analysis.

Table 4: Estimated values of the ideal overall content of L-carnitine in the feed for high performance animals

	Minimum provision or target content[1] of

[1] The target figure consists of the natural content plus the added L-carnitine

Summary

Although animal nutrition is backed up by decades of research, new substances and active drugs are constantly entering established practice. L-carnitine is well on the way to becoming one such substance. L-carnitine acts as an essential natural co-factor in energy metabolism, promoting the integrity and functioning of membranes and protecting nerve cells.

The animal's requirement for L-carnitine is met both by endogenous synthesis and supplementation in the feed. Young animals, in particular, require increased amounts of exogenous L-carnitine since their own synthesis is limited. Concentrations in natural feeds are often inadequate to meet the requirements.

Fertility and reproduction are dependent on a high energy supply rate. The positive effect of L-carnitine supplementation on boars, pregnant and lactating sows and weaners was demonstrated in feeding trials, as reported in this article.

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