Aus dem Institut für Ernährungswissenschaften
(Direktor: Prof. Dr. habil. Klaus Eder)
der
Landwirtschaftlichen Fakultät
(Dekan: Prof. Dr.-Ing. Peter Pickel)
der
Martin-Luther-Universität
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Experimentelle Untersuchungen zur Wirkung von L-Carnitinsupplementierungen bei Sauen und deren Ferkeln

Dissertation

zur Erlangung des akademischen Grades
doctor agriculturarum (Dr. agr.)

von Diplomagraringenieur
Carmen Birkenfeld

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Carmen Birkenfeld

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Gutachter: Prof. Dr. habil. K. Eder
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Inhaltsverzeichnis

Abkürzungsverzeichnis

ANOVA	Analysis of variance
ATP	Adenosin-Triphosphat
bzw.	beziehungsweise
ca.	circa
CoA	Coenzym A
CPT-1	Carnitin-Palmitoyl-Transferase-1
d	Tag
et al.	et allii (und andere)
FSH	Follikelstimulierendes Hormon
g	Gramm
GLUT-1	Glukosetransporter-1
GnRH	Gonadotropin Realising Hormon
h	Stunde
hCG	humanes Chorion Gonadotropin
IgA	Immunglobulin A
IGF-1	insuline-like growth factor-1
IGFBP	insulin-like growth factor binding protein
IU	International Unit
kg	Kilogramm
L	Liter
LH	Luteinisierendes Hormon
ME	Umsetzbare Energie
mg	Milligramm
min	Minuten
MJ	Megajoule
mm	Millimeter
mL	Milliliter
n	Stichprobenumfang
nmol	Nanomol
P	Irrtumswahrscheinlichkeit
pGH	porcine growth hormone
PMSG	Pregnant Mares Serum Gonadotropin
p.p.	post partum
SD	Standarddifferenz
SE	Standardfehler
SEM	gepoolter Standardfehler
STREB	sterol regulatory element binding proteins
µmol	Mikromol

1. Einleitung und Zielstellung

L-Carnitin, chemisch 3-Hydroxy-4-Trimethyl-Ammoniumbutyrat, ist eine, sowohl im menschlichen als auch im tierischen Organismus natürlich vorkommende Substanz. Bereits 1905 wurde das L-Carnitin von den russischen Wissenschaftlern GULEWITSCH und KRIMBERG entdeckt und erstmalig aus Fleischextrakt isoliert. Im Intermediärstoffwechsel erfüllt L-Carnitin eine Vielzahl von verschiedenen Funktionen. Beispielsweise ist das Carnitin-System (Carnitin-Palmitoyl-Transferase I/II, Carnitintranslokase) im Lipidstoffwechsel für den Transport aktivierter Fettsäuren durch die innere Mitochondrienmembran essentiell und damit eine unverzichtbare Voraussetzung für den Abbau von Fettsäuren durch die ß-Oxidation und die damit verbundene Energiegewinnung (FRITZ 1955, 1963, BREMER 1963, BORUM 1983). Hierfür wird L-Carnitin nur in verhältnismäßig geringen Mengen benötigt, nicht verbraucht und steht für diese Funktion während des Prozesses immer wieder zur Verfügung. Ferner ist seine metabolische Funktion als Acetylpuffer zur Aufrechterhaltung des Acetyl-CoA/CoA Verhältnisses von spezieller Bedeutung (KERNER und HOPPEL 1998). Durch die Aktivität von 3 spezifischen Transferasen mit unterschiedlichen, sich teilweise überlappenden Substrat-Spezifitäten (Carnitin-Acetyl-Transferase, Carnitin-Octanoyl-Transferase, Carnitin-Palmitoyl-Transferase) können toxische oder schwer zu verstoffwechselnde, bereits aktivierte Säuren aus den Mitochondrien, aus den Zellen und letztlich aus dem Organismus ausgeschleust werden (REBOUCHE und SEIM 1998). Bei diesem Vorgang wird freies Carnitin zu Acetylcarnitin umgesetzt und dabei in größeren Mengen benötigt (HARMEYER 1998). Weiterhin ist L-Carnitin an der Regulierung des oxidativen Glucoseabbaus, der Decarboxylierung von verzweigtkettigen Aminosäuren sowie an der Ketogenese beteiligt. Außerdem übt L-Carnitin einen stabilisierenden Effekt auf die Zellmembranen aus (SEWELL und BÖHLES 1995).

Neben der Aufnahme von L-Carnitin über die Nahrung, ist der Säugetierorganismus in der Lage diese Substanz in der Leber, sowie als Vorstufe in der Niere, zu synthetisieren. Als Vorstufen dienen hierbei die essentiellen Aminosäuren L-Methionin und L-Lysin (BREMER 1963) sowie die Vitamine B_6, C, Niacin und das Spurenelement Eisen als Katalysatoren (BORUM 1983, HARMEYER und SCHLUMBOHM 1997). Bei Neugeborenen ist die körpereigene Biosynthese von L-Carnitin noch relativ schwach entwickelt (BORUM 1983). Daher sind sie in besonderem Maße auf eine Zufuhr über die Muttermilch angewiesen (COFFEY et al. 1991), in der diese Substanz in relativ hohen Konzentrationen enthalten ist (ERFLE et al. 1974, SNOSWELL et al. 1975, KERNER et al. 1984). L-Carnitin befindet sich vorwiegend in tierischen Produkten (HARMEYER 1998), pflanzliche Produkte enthalten nur wenig oder gar kein L-Carnitin (BORUM 1979, KERNER et al. 1984). Somit sind Pflanzenfresser in stärkerem Maße auf eine körpereigene Synthese angewiesen als Fleischfresser (HARMEYER und SCHLUMBOHM 1997). Futtermittelrechtlich wird diese Substanz, welche in ihrer Struktur einer Aminosäure ähnlich ist, in die Gruppe der Vitamine, Provitamine und ähnlich wirkende Stoffe eingeordnet.

Die grundlegende Funktion von L-Carnitin im Fett- und Energiestoffwechsel der Zellen hat diese Substanz für den Einsatz bei landwirtschaftlichen Nutztieren besonders interessant gemacht. In den letzten Jahren wurden vermehrt Versuche durchgeführt, die der Frage nachgingen, ob eine

Supplementierung des Futters mit L-Carnitin bei Nutztieren zu Leistungssteigerungen führt. Entsprechende Studien wurden an Sportpferden (FOSTER et al. 1989a, b, RIVERO et al. 2002, ZEYNER et al. 1999), Milchvieh und Mastrindern (LA COUNT et al. 1995, GREENWOOD et al. 2001, CITIL et al. 2003), Legehennen und Broilern (LEIBETSEDER et al. 1995, HARMEYER und BAUMGARTNER 1998, BUYSE et al. 2001, RODEHUTSCORD et al. 2002, CELIK und OZTURKCAN 2003), Mastschweinen (OWEN et al. 1994, 2001a, b), Saug- und Absetzferkeln (HOFFMANN et al. 1993, OWEN et al. 1996, HEO et al. 2000a, b, 2002) und Ebern (KOZINK et al. 2004) durchgeführt. Speziell bei Sauen wurden in letzter Zeit positive Wirkungen einer L-Carnitinzulage zum Futter auf die Reproduktions- und Aufzuchtleistung festgestellt (HARMEYER 1993, MUSSER et al. 1999a, b, EDER et al. 2001, RAMANAU et al. 2002, 2004, 2005).
So führte ein Zusatz von L-Carnitin zum Sauenfutter beispielsweise zu einer niedrigeren Anzahl an lebensschwachen und zu einer höheren Anzahl an abgesetzten Ferkeln (MUSSER et al. 1999a, EDER et al. 2001). Zudem konnte gezeigt werden, dass Ferkel, deren Muttersauen während der Trächtigkeit L-Carnitingaben erhielten, deutlich höhere Geburtsgewichte aufwiesen als Ferkel von unbehandelten Sauen (MUSSER et al. 1999a, EDER et al. 2001, RAMANAU et al. 2002). Jedoch sind die Ursachen der Leistungssteigerungen bei Sauen und Ferkeln durch L-Carnitinzulagen bislang nicht vollends geklärt. Aus diesem Grund sollten in der vorliegenden Arbeit die Untersuchungen zur Wirkung von L-Carnitinsupplemetierungen bei Sauen und Ferkeln weiter vertieft werden. Insgesamt wurden im Rahmen dieser Arbeit fünf Studien durchgeführt, mit dem Ziel weitere Erkenntnisse zu den Ursachen der vielfach festgestellten positiven Wirkung von L-Carnitin im Sauen- und Ferkelbereich zu gewinnen.

In zahlreichen Untersuchungen zeichneten sich Ferkel von mit L-Carnitin supplementierten Sauen durch höhere Lebendmassezunahmen während der Säugeperiode aus als Ferkel von Kontrollsauen (EDER et al. 2001, RAMANAU et al. 2002, 2004, 2005). Jedoch wurde bisher nicht untersucht, ob dieser Wachstumsvorteil erhalten bleibt und Ferkel von mit L-Carnitin behandelten Sauen im Vergleich zu Ferkeln von Kontrollsauen auch nach dem Absetzen ein besseres Wachstum aufweisen. Zudem existieren Untersuchungen, in denen gezeigt werden konnte, dass die Wachstumsleistung von Ferkeln nach dem Absetzen durch eine L-Carnitinsupplementierung des Ferkelfutters gesteigert werden kann (OWEN et al. 1996, HEO et al. 2000a, b). Es stellte sich die Frage, ob Ferkel von Sauen, die während der Trächtigkeit und Laktation L-Carnitingaben erhielten auch nach dem Absetzen eine verbesserte Wachstumsrate aufweisen oder ob diese vorrangig durch eine Zulage von L-Carnitin zum Ferkelfutter beeinflusst wird. Die Zielstellung der ersten Studie (2.1.) bestand somit darin, neben dem Effekt einer L-Carnitinsupplementierung des Sauenfutters, auch die Wirkung von L-Carnitinzulagen zum Ferkelfutter auf die Wachstumsleistung der Ferkel nach dem Absetzen zu untersuchen. In 2 Durchgängen wurden Ferkel von Jungsauen (Durchgang 1) und Ferkel aus dem 2. Wurf derselben Sauen (Durchgang 2) in 4 Gruppen so eingeteilt, dass die mittleren Ferkelgewichte innerhalb der Gruppen zu Versuchsbeginn gleich waren. Ferkel von Kontrollsauen und Ferkel von mit L-Carnitin behandelten Sauen (Trächtigkeit: 125 mg L-Carnitin/Tier & Tag; Laktation: 250 mg L-Carnitin/Tier & Tag) erhielten ein adäquates

Ferkelfutter ohne und mit L-Carnitinzusatz (Behandlungsgruppe: 30 mg L-Carnitin/kg Futter) ad libitum angeboten. Zur Beurteilung der Wachstumsleistung der Ferkel wurde die Entwicklung der Lebendmasse sowie die Merkmale tägliche Lebendmassezunahme, tägliche Futteraufnahme und Futterverwertung berücksichtigt. Weitere Details zu Material und Methodik sowie die ausführliche Beschreibung und Diskussion der Ergebnisse dieser Studie sind ersichtlich in:

Birkenfeld C, Ramanau A, Kluge H, Spilke J, Eder K (2005): *Effect of dietary L-carnitine supplementation on growth performance of piglets from control sows or sows treated with L-carnitine during pregnancy and lactation.* ***Journal of Animal Physiology and Animal Nutrition*** *89, 277-283.*

Die in bisherigen Untersuchungen festgestellten erhöhten Geburtsgewichte (MUSSER et al. 1999a, EDER et al. 2001, RAMANAU et al. 2002) und Lebendmassezunahmen (EDER et al. 2001, RAMANAU et al. 2002, 2004, 2005) der Ferkel und Würfe von mit L-Carnitin supplementierten Sauen deuten auf ein verbessertes prä- und postnatales Wachstum der Ferkel von behandelten Sauen hin. Die Ursachen hierfür sind bislang jedoch nicht völlig geklärt. In Untersuchungen von MUSSER et al. (1999a) konnte gezeigt werden, dass mit L-Carnitin behandelte Sauen während der Trächtigkeit höhere Konzentrationen an Insulin und IGF-1 (insulin-like growth factor-1) im Blut aufweisen als Kontrollsauen. Während die Funktion des Insulins darin besteht, die Protein- und Lipidsynthese zu erhöhen, steigert das IGF-1 den Proteinzuwachs im Ferkelkörper (GLUCKMAN 1997). Demnach könnte das verbesserte Wachstum der Ferkel während der Säugeperiode von mit L-Carnitin behandelten Sauen möglicherweise auf eine günstigere Körperzusammensetzung der Ferkel bereits zur Geburt zurückzuführen sein. Bisher wurde jedoch nicht untersucht, ob Ferkel von supplementierten Sauen eine veränderte Körperzusammensetzung aufweisen oder sich in Bezug auf metabolische Parameter von Kontrollferkeln zur Geburt und während der Säugeperiode unterscheiden. Zudem existieren Untersuchungen in denen eine L-Carnitinsupplementierung bei Absetzferkeln und Mastschweinen, als Folge einer gesteigerten ß-Oxidationsrate aufgrund einer erhöhten CPT-1 Aktivität, tatsächlich zu geringeren Gehalten an Körperfett im Ganzkörper führt (HEO et al. 2000, OWEN et al. 1996, 2001). Das Ziel der zweiten Studie (2.2.) war es daher, zu untersuchen, ob eine Supplementierung von Sauen mit L-Carnitin während der Trächtigkeit und Laktation zu Veränderungen der Körperzusammensetzung sowie des Lipidmetabolismus von neugeborenen und Saugferkeln führt. Hierfür wurde ein Versuch mit insgesamt 27 Jungsauen der Rasse (Deutsches Edelschwein x Deutsche Landrasse) durchgeführt, welche unter Berücksichtigung der Lebendmasse und des Alters in eine Versuchsgruppe (n=14) und eine Kontrollgruppe (n=13) eingeteilt und mit Pietrain Ebersperma besamt wurden. Allen Sauen wurde während der Trächtigkeit und Laktation jeweils ein handelsübliches Futter mit geringem nativen L-Carnitingehalt angeboten (Trächtigkeitsfutter: 10 mg/kg; Laktationsfutter: 3 mg/kg). Den Sauen der Versuchsgruppe wurde zusätzlich zur Basisdiät während der Trächtigkeit 125 mg L-Carnitin pro Tier und Tag und während der Laktation 250 mg L-Carnitin pro Tier und Tag verabreicht. Für die Analyse der Körperzusammensetzung wurde jeweils zur Geburt, am 10. sowie am 20. Lebenstag

aus jedem Wurf ein Ferkel entnommen, welches dem mittleren Ferkelgewicht des jeweiligen Wurfes entsprach. Da L-Carnitin im Lipidstoffwechsel involviert ist, wurden ferner metabolische Parameter wie die Konzentrationen an Triglyceriden, Cholesterol und freien Fettsäuren in der Leber und dem Plasma der Ferkel zur Geburt und während der Säugeperiode bestimmt. Weitere Details zu Material und Methodik sowie die ausführliche Beschreibung und Diskussion der Ergebnisse dieser Studie sind ersichtlich in:

Birkenfeld C, Doberenz J, Kluge H, Eder K (2006): *Effect of L-carnitine supplementation of sows on L-carnitine status, body composition and concentrations of lipids in liver and plasma of their piglets at birth and during the suckling period.* ***Animal Feed Science and Technology****. (online publiziert)*

Das postnatale Wachstum der Ferkel ist abhängig von der Milchproduktion der Sau (NOBLET and ETIENNE 1987, KING et al. 1993) sowie der Energie- und Nährstoffaufnahme der Ferkel mit der Sauenmilch, welche in den ersten Lebenstagen die einzige Nahrungsquelle für die Ferkel darstellt. RAMANAU et al. (2004, 2005) stellten in ihren Untersuchungen mit Hilfe der „weigh-suckle-weigh“ Methode tatsächlich fest, dass mit L-Carnitin supplementierte Sauen eine höhere Milchleistung aufweisen als Kontrollsauen. Die Milchleistung der Sau wird entscheidend vom Säugeverhalten der Ferkel beeinflusst. Ferkel, die öfter und intensiver Säugen, mit kürzeren Intervallen zwischen den Saugakten, sind in der Lage, mehr Milch aufzunehmen und gleichzeitig die Milchsynthese anzuregen (AULDIST et al. 1998, SPINKA et al. 1997). Zielstellung der dritten Studie (2.3.) war es daher zu untersuchen, ob die verbesserte Milchleistung der mit L-Carnitin supplementierten Sauen auf ein verändertes Säugeverhalten der Ferkel zurückzuführen sein könnte. Hierfür wurden 2 Experimente mit Sauen durchgeführt, die in eine Versuchsgruppe und eine Kontrollgruppe zu jeweils 13 Tieren (Experiment 1) bzw. zu jeweils 10 Tieren (Experiment 2) eingeteilt und mit handelsüblichem Futter gefüttert wurden. Die Sauen der Versuchsgruppe erhielten wie in den vorangegangenen Untersuchungen während der Trächtigkeit 125 mg L-Carnitin pro Tier und Tag und während der Laktation 250 mg L-Carnitin pro Tier und Tag oral verabreicht. Nach der Geburt wurden alle Würfe auf 11 Ferkel (Experiment 1) bzw. 9 Ferkel (Experiment 2) pro Wurf standardisiert. Im ersten Versuch wurde mittels Videoaufzeichnungen das Säugeverhalten der Ferkel beider Behandlungsgruppen am 3., 6. und 9. Lebenstag beobachtet und die Anzahl der Saugakte, die mittlere Säugezeit pro Saugakt sowie die Gesamtsäugezeit pro Tag ermittelt. Hierbei sollte die Frage beantwortet werden, ob ein verändertes Säugeverhalten der Ferkel von mit L-Carnitin behandelten Sauen als ursächlich für das verbesserte Wachstum während der Säugezeit anzusehen ist. Zudem ist bislang ungeklärt, ob die verbesserte Wachstumsleistung der Ferkel während der Säugeperiode durch einen vorrangig prä- oder postnatalen Einfluss des L-Carnitins hervorgerufen wird. Einerseits könnte eine L-Carnitinsupplementierung von Sauen während der Trächtigkeit die pränatale Entwicklung der Föten fördern und die Vitalität der Ferkel zur Geburt sowie die Säugeaktivität verbessern. Alternativ könnte eine gesteigerte Säugeaktivität der Ferkel auch durch eine L-Carnitinsupplementierung von Sauen während der Laktation verursacht werden, in dessen Folge Ferkel mehr L-Carnitin über die Sauenmilch aufnehmen,

dementsprechend einen höheren L-Carnitinstatus aufweisen und somit in der Lage sind länger oder öfter das Gesäuge der Sau aufzusuchen. Um diese beiden Hypothesen zu überprüfen, wurde ein zweiter Versuch unter den gleichen Versuchsbedingungen durchgeführt, bei dem eine Hälfte der zu beobachtenden Würfe innerhalb der Behandlungsgruppen und die andere Hälfte der zu beobachtenden Würfe zwischen den Behandlungsgruppen ausgetauscht wurde, sodass jede Sau die gleiche Anzahl an Ferkel einer fremden Sau führte. Die Würfe der 4 gebildeten Gruppen wurden am 3. Lebenstag über einen Zeitraum von 24 Stunden gefilmt und ebenfalls die Anzahl der Saugakte, die mittlere Säugezeit pro Saugakt sowie die Gesamtsäugezeit pro Tag ermittelt. Zusätzlich wurde der Gehalt an L-Carnitin in der Sauenmilch sowie im Plasma der Ferkel jeweils zur Geburt, am 14. und am 28. Laktationstag bestimmt. Weitere Details zu Material und Methodik sowie die ausführliche Beschreibung und Diskussion der Ergebnisse dieser Studie sind ersichtlich in:

Birkenfeld C, Kluge H, Eder K (2006): *L-carnitine supplementation of sows during pregnancy improves the suckling behaviour of their offspring.* ***British Journal of Nutrition.*** *(Manuskript akzeptiert zur Publikation 2006)*

Neben einer erhöhten Milchleistung der Sau könnte auch eine veränderte Zusammensetzung der Sauenmilch grundlegend für die gesteigerten Lebendmassezunahmen der Ferkel während der Säugezeit sein. RAMANAU et al. (2004, 2005) konnten am 11. Laktationstag hinsichtlich des Energiegehaltes und des Gehaltes an Inhaltsstoffen der Milch von supplementierten und unbehandelten Sauen keine Unterschiede feststellen. Ob eine L-Carnitinsupplementierung von Sauen die Zusammensetzung der Milch zu einem früheren Zeitpunkt beeinflusst, wurde bisher noch nicht untersucht. Es schloss sich eine vierte Studie (2.4.) an, welche das Ziel verfolgte den Einfluss einer L-Carnitinsupplementierung bei Sauen auf die Zusammensetzung und den Gehalt an Inhaltsstoffen im Kolostrum und der Milch zu prüfen. Milchproben von 13 Kontrollsauen und 14 mit L-Carnitin supplementierten Sauen (Trächtigkeit: 125 mg L-Carnitin/Tier & Tag; Laktation: 250 mg L-Carnitin/Tier & Tag) wurden 5-8 Stunden nach der Geburt (Kolostrum) sowie am 10. und 20. Laktationstag gewonnen. Speziell wurden die Konzentrationen an Protein, Fett und Laktose in der Milch bestimmt. Das Kolostrum wurde zusätzlich auf den Gehalt an Immunglobulinen (IgG, IgM, IgA) untersucht, welche für die passive Immunisierung und letztendlich für die Vitalität der Ferkel von besonderer Bedeutung sind. Zusätzlich wurde das Säugeverhalten der Ferkel am 3. Lebenstag untersucht, um die in der vorangegangenen Studie (2.3.) gefundenen Ergebnisse zu bestätigen. Weitere Details zu Material und Methodik sowie die ausführliche Beschreibung und Diskussion der Ergebnisse dieser Studie sind ersichtlich in:

Birkenfeld C, Kluge H, Eder K: *Effect of L-carnitine supplementation on the nutrient composition of the milk in sows.* ***Archives of Animal Nutrition.*** *(Manuskript akzeptiert zur Publikation 2006).*

In zahlreichen bisherigen Untersuchungen zeigte sich ein positiver Effekt einer L-Carnitinsupplementierung auf die Reproduktionsleistung von Sauen, in Form von höheren Geburtsgewichten der Ferkel und Würfe, weniger totgeborenen oder mehr lebendgeborenen Ferkeln sowie gesteigerten Lebendmassezunahmen der Ferkel während der Säugezeit (MUSSER et al. 1999a, b, EDER et al. 2001, RAMANAU et al. 2002, 2004, 2005). Demnach scheint L-Carnitin das Fruchtbarkeitsgeschehen von Sauen positiv zu beeinflussen. Neben der Anzahl und dem Gewicht der Ferkel zur Geburt und dem postnatalen Wachstum der Ferkel ist die Trächtigkeitsrate bzw. die Anzahl an besamten Sauen, die tragend werden, von besonderer ökonomischer Bedeutung für die Schweineproduktion. Bisher wurde die Wirkung von L-Carnitin auf die Trächtigkeitsrate von Sauen jedoch nicht untersucht. In einer fünften Studie (2.5.) wurden daher drei Experimente zusammengefasst, um den Effekt von L-Carnitin auf die Trächtigkeitsrate, die Wurfgröße und die Wurfgewichte anhand einer hohen Tieranzahl zu überprüfen. Die 3 Experimente wurden mit Sauen durchgeführt, welchen während der Trächtigkeit und Laktation handelsübliches Futter verabreicht wurde. Die Sauen der Versuchsgruppe erhielten pro Tier und Tag zusätzlich 125 mg L-Carnitin während der Trächtigkeit und 250 mg L-Carnitin während der Laktation. Alle drei Experimente erstreckten sich jeweils über drei aufeinander folgende Reproduktionszyklen und wiesen den gleichen Versuchsaufbau auf. Insgesamt wurden in der Kontrollgruppe 93 Sauen und in der Versuchsgruppe 111 Sauen tragend. Weitere Details zu Material und Methodik sowie die ausführliche Beschreibung und Diskussion der Ergebnisse dieser Studie sind ersichtlich in:

Birkenfeld C, Kluge H, Eder K: *Effect of L-carnitine supplementation on pregnancy rate, litter sizes and litter weights in sows.* **Animal Feed Science and Technology.** *(Manuskript eingereicht zur Publikation 2006).*

Originalarbeit I

Effect of dietary L-carnitine supplementation on growth performance of piglets from control sows or sows treated with L-carnitine during pregnancy and lactation

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SUMMARY
Previous studies showed that supplementation of sows´ diets with L-carnitine increases body weights of their piglets at birth. This study was performed to investigate whether piglets of sows treated with L-carnitine differ in their growth potential from that of piglets of untreated control sows after weaning. It was also investigated whether supplementation of piglets´ diets with L-carnitine improves their growth after weaning. In two trials, piglets of the first litters of primiparous sows (Trial 1) and the second litters of the same sows (Trial 2) were divided into four groups: group 1, piglets of control sows, fed a control diet; group 2; piglets of control sows fed a diet supplemented with 30 mg L-carnitine/kg; group 3, piglets of L-carnitine treated sows, fed a control diet; group 4; piglets of L-carnitine treated sows fed a diet supplemented with 30 mg L-carnitine/kg. Mean initial body weights of the piglets of the four groups were identical. They were 8.5 kg in Trial 1 and 12.5 kg in Trial 2. Diets were fed ad-libitum over a period of 35 days. Piglets from sows treated with L-carnitine did not differ in body weight gains, feed intake and gain:feed ratio from those of control sows. In Trial 1, piglets supplemented with L-carnitine had higher body weight gains ($P<0.005$) and showed a tendency towards a higher gain:feed ratio ($P=0.09$) than piglets fed the control diets. In Trial 2, no significant difference in these parameters emerged between piglets fed the diet supplemented with L-carnitine and those fed the control diet. In conclusion, this study shows that dietary L-carnitine treatment of sows does not improve the growth potential of their piglets after weaning under the conditions of equal initial body weights. The study also shows that L-carnitine supplementation of their diets improves the growth performance in light piglets of primiparous sows.

Running title: “L-carnitine in pigs”

INTRODUCTION
Recent studies demonstrated that L-carnitine supplementation of sows during pregnancy increases birth weight of piglets (MUSSER et al. 1999a; EDER et al. 2001; RAMANAU et al. 2002). This suggests that L-carnitine influences the intrauterine development of the fetus. MUSSER et al. (1999a) observed increased concentrations of IGF-1 in blood of sows treated with L-carnitine. These authors suggested that L-carnitine supplementation of sows stimulated fetal muscle fiber development (MUSSER et al. 1999b). Their suggestion would implicate that piglets of sows treated with L-carnitine possess a higher growth capability in the postnatal state. We observed that piglets of sows treated with L-carnitine indeed grew faster during the suckling period than piglets of untreated control sows (EDER et al. 2001; RAMANAU et al. 2004). This effect, however, is the result of a higher milk production of sows treated with L-carnitine (RAMANAU et al. 2004). Until now, it has not been investigated whether piglets of L-carnitine treated sows have a higher growth performance after weaning than piglets of control sows. Some previous studies demonstrated that L-carnitine supplementation of piglets´ diets after weaning improves the gain:feed ratio (OWEN et al. 1996) or nitrogen utilization and average daily body weights (HEO et al. 2000a). We intended to find out whether piglets of sows supplemented with L-carnitine have a higher growth rate after weaning than those of control sows, and whether this effect is influenced by dietary L-carnitine supplementation of piglets´ diets. Therefore, we conducted trials in which piglets of control sows and piglets of L-carnitine treated sows were fed nutritionally adequate piglet diets with or without L-carnitine supplements. To assess growth performance of the piglets we determined body weight gains, feed intake and gain:feed ratios of the piglets.

MATERIALS UND METHODS
The piglets used in this study originated from cross-breed sows (German land race X Large white) which were used in a recent study which investigated the effect of L-carnitine treatment of sows on their reproductive performance (RAMANAU et al. 2004). In that experiment, control sows received during pregnancy and lactation nutritionally adequate diets with relatively low basal concentrations of L-carnitine (16 and 4 mg/kg in the pregnancy and the lactation diets, respectively). Sows treated with L-carnitine received the same basal experimental diets, but they received additionally 125 and 250 mg of L-carnitine per day during pregnancy and lactation, respectively. Experimental conditions and results of sows´ reproductive performance have been recently published (RAMANAU et al. 2004). The sow experiment was conducted over two consecutive reproductive cycles. The

first cycle included 13 primiparous sows in each group; among those sows 10 of each group were investigated in the second cycle. Table 1 gives an overview about body weights of these sows at various time points, the number of piglets born and weights of piglets at weaning in the first and the second reproductive cycle.

Table 1: Number of piglets and weights of piglets at birth and at weaning in control sows and sows supplemented with L-carnitine at the first and the second reproductive cycle

Cycle	First		Second	
Treatment of sows	Control	+ L-carnitine	Control sows	+ L-carnitine
Body weights of sows, day 1 of pregnancy, kg	145 ± 3[b]	144 ± 3[b]	172 ± 3[a]	172 ± 3[a]
Body weights of sows, day 110 of pregnancy, kg	220 ± 4[b]	222 ± 4[b]	262 ± 4[a]	266 ± 4[a]
Body weights of sows, at weaning, kg	171 ± 5[b]	166 ± 5[b]	207 ± 5[a]	210 ± 5[a]
Number of piglets born, n	10.2 ± 0.8[b]	12.9 ± 0.7[a]	10.8 ± 0.9[b]	13.5 ± 0.9[a]
Number of piglets born alive, n	9.6 ± 0.8[b]	12.4 ± 0.8[a]	10.3 ± 0.9[b]	13.1 ± 0.9[a]
Weights of piglets at birth, kg	1.54 ± 0.06	1.39 ± 0.06	1.70 ± 0.07	1.53 ± 0.07
Weights of piglets at weaning, kg	7.60 ± 0.21	8.11 ± 0.21	10.81 ± 0.24	11.43 ± 0.24

*Data are least square means ± standard errors of means. Mean values within the same column lacking a common superscript are significantly different (P≤0.05)

Between control sows and sows supplemented with L-carnitine, there were no differences in body weights at day 1 and day 110 of pregnancy and at weaning. In both cycles, sows supplemented with L-carnitine had a higher number of piglets born and piglets born alive. In both parturitions, piglets of sows supplemented with L-carnitine were slightly lighter at birth than those of control sows. Piglets of the first parturition were weaned after a 25-day suckling period; piglets of the second parturition were weaned for technical reasons after a longer suckling period of 30 days. In both cycles, piglets of sows supplemented with L-carnitine were slightly heavier at weaning than those of control sows. We used piglets of the first and the second parturition. After weaning, all the piglets were fasted for 24 hours and were then fed the basal experimental diet without L-carnitine supplementation (see below) for two days. Then three or four piglets from each sow were selected on the basis of their body weights. They were allotted to four groups of 18 piglets each: Group 1 and 2 were piglets of control sows; groups 3 and 4 were piglets of L-carnitine treated sows. To eliminate the effect of different initial body weights of piglets, piglets were selected to give groups with identical average body weights. It should be noted that these groups did not exactly represent average body weights of the piglets of control sows and those of L-carnitine treated sows. The animals were kept in environmentally controlled housing in flatdeck pens with 2 animals per pen. The building and flatdeck pens were disinfected before commencement of the trial. The temperature was 26°C during the first week of the experiment and then gradually reduced to 22°C. The relative humidity was between 55 and 60%. The basal experimental diet used in both trials was nutritionally adequate for piglets. It consisted of (in g/kg): wheat (300), extracted soybean meal (200), barley (120), peas (100), rye (100), maize (68.6), wheat bran (50), soy oil (30), vitamin and mineral mixture (25), L-lysine-HCl (3), dicalcium phosphate (2), L-threonine (0.8), DL-methionine (0.6). Concentrations of major nutrients were (g/kg): Crude protein (215), Crude fat (57), crude ash (56), lysine (11.7), calcium (7.1), phosphorus (6.0). The calculated content of metabolizable energy was 13.6 MJ/kg diet. The L-carnitine concentration of the basal diet was 4 mg/kg. Piglets of groups 1 and 3 were fed the basal diets; piglets of groups 2 and 4 received the basal diets supplemented with 30 mg L-carnitine per kg (Carniking, Lohmann Animal Health, Cuxhaven, Germany). Diets were administered ad-libitum over a period of 35 days. Unconsumed feed was weighed weekly in experiments. Water was available ad libitum from a nipple drinker system. The animals were weighed weekly. Piglets which became diarrhoea or got sick during the experimental period were removed from the experiment. In the first trial, two animals (one of group 1, one of group 4) were

removed for these reasons, in the second trial, six piglets (one of group 1, two of group 2, two of group 3, one of group 4) were removed. Therefore, 70 piglets were evaluated in the first trial for their growth performance, and 66 piglets were evaluated in the second trial.
The statistical analysis of the data was performed with the SAS package (procedure mixed, version 8.2, SAS Institute, Cary, NC, U.S.A). A mixed linear model with four fixed effects, and depending on the trait under investigation one or two random effects was used. Sows´ diet (control, + L-carnitine), piglets´ diet (control, + L-carnitine), the trial effect and the interaction between these factors were included as fixed effects. Because several piglets of one sow were used, for traits observable on the piglet level besides the random error effect a random sow effect was included in the model. Because the data are unbalanced, we used as method of variance component estimation REML and for degrees of freedom approximation in hypothesis tests the method described by KENWARD and ROGER (1997). For statistical significant F values, individual means were compared by Tukey-Kramer test to ensure experiment wise control of statistical error 1st kind. Values in the text are least square means ± standard errors of means.

RESULTS
The initial body weights of the piglets (day 0) were similar in the four groups of piglets (Table 2) as result of the piglet selection and allotment to the groups (see Material and Methods).

Table 2: Effect of dietary L-carnitine supplementation of sows´ and/or piglets´ diets on body weight development of piglets

Effect			Day 0	Day 7	Day 14	Day 21	Day 28	Day 35
					F-test (P-values)			
Sows´ diet			0.69	0.36	0.40	0.37	0.33	0.14
Piglets´ diet			0.79	0.39	0.06	0.38	0.42	0.05
Trial			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Sow´s diet x piglets´ diet			0.50	0.41	0.97	0.39	0.53	0.46
Sows´diet x trial			0.06	0.66	0.68	0.90	0.77	0.88
Piglet´s diet x trial			0.43	0.88	0.73	0.45	0.10	0.04
Main Effects*		n			Kg			
Sows´diet								
Control		68	10.5 ± 0.1	11.4 ± 0.1	13.6 ± 0.2	16.4 ± 0.3	21.2 ± 0.4	26.7 ± 0.5
+ L-carnitine		68	10.5 ± 0.1	11.2 ± 0.1	13.3 ± 0.2	16.0 ± 0.3	20.6 ± 0.4	25.6 ± 0.5
Piglets´diet								
Control		68	10.5 ± 0.1	11.2 ± 0.1	13.2 ± 0.2	16.1 ± 0.3	20.8 ± 0.4	25.7 ± 0.4^{b}
+ L-carnitine		68	10.5 ± 0.1	11.3 ± 0.1	13.7 ± 0.2	16.4 ± 0.3	21.1 ± 0.4	26.6 ± 0.4^{a}
Trial								
1		70	8.5 ± 0.1^{b}	9.6 ± 0.1^{b}	11.2 ± 0.2^{b}	13.7 ± 0.3^{b}	17.8 ± 0.4^{b}	22.8 ± 0.5^{b}
2		66	12.5 ± 0.1^{a}	12.9 ± 0.2^{a}	15.7 ± 0.2^{a}	18.8 ± 0.3^{a}	24.0 ± 0.4^{a}	29.5 ± 0.5^{a}
Treatment groups*								
Group	Sows´ diet	Piglets´ diet						
1	Control	Control	34	10.4 ± 0.1	11.3 ± 0.1	13.4 ± 0.3	16.2 ± 0.4	20.9 ± 0.5	26.0 ± 0.6^{ab}
2	Control	+ L-carnitine	34	10.5 ± 0.1	11.5 ± 0.1	13.8 ± 0.3	16.7 ± 0.4	21.5 ± 0.5	27.4 ± 0.6^{a}
3	+ L-carnitine	Control	34	10.5 ± 0.1	11.2 ± 0.1	13.1 ± 0.3	16.1 ± 0.4	20.6 ± 0.5	25.3 ± 0.6^{b}
4	+ L-carnitine	+ L-carnitine	34	10.5 ± 0.1	11.2 ± 0.1	13.5 ± 0.3	16.0 ± 0.4	20.6 ± 0.5	25.9 ± 0.6^{ab}

*Data are least square means ± standard errors of means. Mean values within the same column lacking a common superscript are significantly different (P≤0.05).

However, the piglets of the first trial which originated from primiparous sows were initially lighter than those of the second trial which originated from the second litters of the same sows. Piglets of the first trial were also lighter throughout the whole feeding period than those of the second trial. Throughout the whole feeding period, piglets of L-carnitine treated sows did not differ significantly in their body weights from those of control sows. At day 14, piglets treated with L-carnitine showed a tendency towards higher body weights than piglets fed the control diets (P=0.06). At day 35, the effect of L-carnitine on piglets´ body weights was even statistically significant (P=0.05). But at day

35, there was also an interaction between factors piglets´ diet and trial in body weights of piglets. In the first trial, piglets fed diets supplemented with L-carnitine had higher body weights at day 35 than piglets fed the control diets (23.8 ± 0.6 vs. 21.8 ± 0.6 kg, P<0.005); in the second experiment no differences were observed between piglets fed diets supplemented with L-carnitine and piglets fed control diets (29.4 ± 0.6 vs. 29.5 ± 0.6 kg, P=0.92). On days 7, 21 and 28, no differences in body weights were seen between piglets fed the diet supplemented with L-carnitine and piglets fed the control diet. No significant interactions in body weights emerged between the factors sows´ diet and piglets´.

Table 3: Effect of dietary L-carnitine supplementation of sows´ and/or piglets´ diets on daily body weight gains, daily feed intake and feed conversion ratio over the entire feeding period of 35 days

Effect		Body weight gain		Feed intake		Gain:feed ratio	
				F-test (P-values)			
Sows´ diet			0.11		0.30		0.40
Piglets´ diet			0.05		0.17		0.06
Trial			<0.001		<0.001		0.004
Sow´s diet x piglets´ diet			0.61		0.48		0.29
Sows´diet x trial			0.66		0.70		0.19
Piglet´s diet x trial			0.04		0.22		0.61
Main Effects*		n	g/d	n	g/d	n	g/kg
Sows´diet							
Control		68	462 ± 13	34	710 ± 17	34	642 ± 7
+ L-carnitine		68	431 ± 13	34	685 ± 17	34	634 ± 7
Piglets´diet							
Control		68	434 ± 11^{b}	34	681 ± 17	34	629 ± 7
+ L-carnitine		68	460 ± 13^{a}	34	714 ± 16	34	647 ± 7
Trial							
1		70	409 ± 13^{b}	35	620 ± 16^{b}	35	652 ± 6^{a}
2		66	485 ± 14^{a}	33	775 ± 18^{a}	33	623 ± 7^{b}
Treatment groups*							
Group	Sows´ diet	Piglets´ diet					
1	Control	Control	34	446 ± 16	17	684 ± 24	17	638 ± 9
2	Control	+ L-carnitine	34	479 ± 17	17	750 ± 24	17	646 ± 9
3	+ L-carnitine	Control	34	422 ± 16	17	677 ± 24	17	620 ± 9
4	+ L-carnitine	+ L-carnitine	34	441 ± 16	17	693 ± 24	17	647 ± 9

*Data are least square means ± standard errors of means. Mean values within the same column lacking a common superscript are significantly different (P≤0.05).

Piglets in the first trial had a lower feed intake and lower body weight gains but a higher gain : feed ratio than piglets of the second trial (Table 3). Piglets of L-carnitine treated sows did not differ from those of control sows in body weight gains, feed intake and gain : feed ratio over the whole feeding period. Piglets fed the diet supplemented with L-carnitine showed higher body weight gains than piglets fed the control diet (P=0.05). But regarding body weight gains of the piglets, there was an interaction between the factors piglets´ diet and trial. In the first trial, daily body weight gains were higher in piglets fed the diet supplemented with L-carnitine than in piglets fed the control diet (437 ± 16 vs. 381 ± 16 g/d, P<0.005); in the second trial, no differences were seen in daily body weight gains between both groups of piglets (486 ± 20 vs. 484 ± 20 g/d). Piglets whose diet was supplemented with L-carnitine moreover showed a tendency towards a higher gain : feed ratio compared to piglets fed the control diet (P=0.06). The effect of L-carnitine on the gain : feed ratio was also stronger in the first trial (663 ± 9 g vs. 641 ± 9 g/kg, P=0.09) than in the second trial (630 ± 9 vs. 617 ± 10 g/kg, P=0.34). The feed intake was not different between piglets fed the diet supplemented with L-carnitine and those fed the control diet.

DISCUSSION

The present study is the first one which investigated the effect of L-carnitine treatment of sows on the growth capability of their piglets. For this purpose, piglets of carnitine-treated and control sows were selected on the basis of their body weights after weaning and allotted into the for groups so that initial mean body weight of the piglets were equal in the four groups. Equalizing of mean body weights appeared necessary to exclude an influence of different initial body weights of the piglets on their growth performance. We are aware that these piglets do not exactly represent total piglets of both groups with respect to their body weight. At weaning and allotment to the experimental groups, piglets of sows treated with L-carnitine were slightly heavier than those of control sows (RAMANAU et al. 2004). Therefore, the average body weights of piglets of L-carnitine treated used in the trials were slightly below those of total piglets of those sows; average body weights of piglets of control sows was slightly higher than that of total piglets of those sows. We can not exclude the possibility that the results would have differed from those of this study if piglets with body weights exactly representing those of the whole piglets of the respective sows would have been used.

This study shows that piglets of L-carnitine treated sows do not differ in their growth performance after weaning from control piglets. The finding that the feed conversion ratio was not different between piglets of both groups of sows suggests that accretion of protein and fat deposition were not different between both groups of piglets. MUSSER et al. (1999) postulated that piglets of L-carnitine sows have a higher number of muscle fiber than those of control sows. Our data do not support an increased formation of muscle in piglets of sows treated with L-carnitine during growth. However, to obtain definite information about formation of muscle and fat during growth, analysis of protein and fat concentrations in the piglets´ whole body is required.

In this study, piglets of the first and the second litters of sows were investigated for their growth performance. There was a significant effect of the trial indicating that piglets of the second litters grew generally faster than those of the first litter. This effect might be predominately due to the fact that piglets of the first litter were included into the trial at lower body weights than those of the second litters.

In this study, L-carnitine supplementation of their diet had favourable effects on body weight gains and the gain:feed ratio in piglets. However, it is remarkable that the effect of L-carnitine on body weights was seen only in the piglets of the first litters. This could be due to the fact that piglets of the first litters were considerably lighter at the start of the feeding trial than those of the second litters. It has been shown that the ability of piglets to synthesize L-carnitine is particularly low in the first weeks of live and increases thereafter (BORUM 1983). This is also the reason why supplementation of L-carnitine increased the hepatic activity of carnitine-palmitoyl transferase I and the rate of ß-oxidation of long-chain fatty acids particularly in young pigs (WOLFE et al. 1978; KEMPEN and ODLE 1995, PENN et al. 1997, HEO et al. 2000b). To test whether L-carnitine exerts a stronger growth-promoting effect in lighter piglets than in heavier ones, it would be necessary to study the effect of L-carnitine in piglets with a wide range of initial body weights. In our study, the variance of the initial body weights of the piglets within one group was very low (<5%). Therefore, it was not possible to find out a possible correlation between the initial body weight of the animals and the carnitine-induced weight gain within one experiment.

Previously, some other studies have been conducted to investigate the effect of dietary L-carnitine supplementation of piglets (HOFFMAN et al. l993; OWEN et al. 1996, CHO et al., 1999; HEO et al. 2000a). The results of these studies, however, were variable. CHO et al. (1999) observed no appreciable improvement in the performance of 21-d old pigs when 1000 mg/kg carnitine was supplemented into diets containing 17% dried skim milk. Similarly, in the study of HOFFMANN et al. (1993) supplemental L-carnitine (800 mg/kg) did not affect body weight gains, energy or nitrogen utilization in young pigs allowed ad-libitum access to feed. In the contrary, OWEN et al. (1996) reported that supplementation of 500 mg/kg L-carnitine improved gain : feed ratios by 9% in pigs from d 36 to 57 of age when pigs were fed a diet based on corn, soybean meal, dried whey and dried skim milk containing 5% soy oil. This improvement stemmed from reduced feed intake rather than increased average daily growth, suggesting that pigs fed L-carnitine may improve energy utilization from soy oil, but that control pigs fed no L-carnitine may satisfy their energy requirement by increased feed intake. In the study of HEO et al. (2000a) supplementation of a vegetarian diet with 500 mg/kg L-carnitine increased protein accretion and average daily weight gains in 54-d old growing pigs with energy limitation to 85% of ad-libitum consumption. These authors concluded from their findings that L-carnitine improves nitrogen utilization and body weight gains particularly if the intake of metabolisable energy is limited. However, our study in which L-carnitine increased average daily body weight gains in piglets under ad-libitum feed consumption is in contradiction

with this view. Besides the intake of metabolizable energy, several dietary factors could be responsible for the different results obtained in these studies. Among them, the L-carnitine concentration of the basal diet might be the most important one. Unfortunately, most studies dealing with the effects of L-carnitine on growth of pigs did not provide the L-carnitine concentration of the diet. Because feedstuffs of plant origin have much lower concentrations of carnitine than those of animal original, vegetarian diets have usually lower concentrations of carnitine than those containing animal components. The fact that L-carnitine supplementation increased body weight gains of piglets in our study and that of HEO et al. (2000a) could be due to the fact that both of these studies used vegetarian basal diets with low concentrations of L-carnitine. The lacking effect of L-carnitine supplementation on body weight gains in piglets fed diets containing animal products in the studies of OWEN et al. (1996) and CHO et al. (1999) could be due to the higher concentrations of native L-carnitine in the basal diets.

OWEN et al. (1996) suggested that L-carnitine exerts its strongest effect on the growth performance of piglets if the concentration of lysine in the diet is relatively low. Indeed, in studies in which L-carnitine exerted favourable effects on growth or gain:feed ratios, lysine concentrations of the diets were lower than in studies in which L-carnitine failed to improve growth or feed:gain ratio in piglets. Diets used by HOFFMANN et al. (1993) contained 1.65 or 1.85% total lysine from d 0 to 21 after weaning, followed by 1.58 or 1.79% total lysine from d 21 to 42. These levels are higher than those in the study of Owen et al. (1996) (1.35 to 1.45 % from d 0 to 35 after weaning), those in the study of HEO et al. (2000a) (0.9 or 1.2% total lysine) and those in our study (1.13% total lysine). The interaction between the effects of L-carnitine supplementation on growth performance of piglets and the dietary lysine concentration should be given more attention in further investigations.

A common finding in several studies was that pigs fed diets supplemented with L-carnitine had higher rates of protein accretion and lower rates of fat accretion than untreated control pigs (OWEN et al. 1996; HEO et al. 2000a, OWEN et al. 2001a, OWEN et al. 2001b). These effects have been attributed to an increased ß-oxidation of fatty acids which favour the formation of protein (OWEN et al. 2001a). We did not measure protein and fat retention of the piglets but an improved utilization of nutrients for growth in piglets supplemented with L-carnitine indeed could be due to an increased protein accretion and a reduced fat deposition.

In conclusion, the present study did not find favourable effects of L-carnitine supplementation of sows on growth performance of their piglets after weaning. L-carnitine supplementation of piglets´ diets, however, increased body weight gains and feed utilization, particularly in light piglets.

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Originalarbeit II

Effect of L-carnitine supplementation of sows on L-carnitine status, body composition and concentrations of lipids in liver and plasma of their piglets at birth and during the suckling period

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ABSTRACT
Previous studies have shown that supplementation of sow diets with L-carnitine increases body weights of their piglets at birth. It has not yet been investigated whether piglets of sows supplemented with L-carnitine differ in their body composition or metabolic parameters from those of control sows at birth and during the suckling period. This study was performed to investigate whether supplementation of sows with L-carnitine during pregnancy and lactation influences body composition and lipid metabolism of their piglets. An experiment was conducted with 40 primiparous sows which were assigned to two groups of 20 sows each and had free access to a nutritionally adequate diet. One group was supplemented with 125 mg L-carnitine/day during pregnancy and 250 mg L-carnitine/day during lactation; the other group (control group) did not receive L-carnitine. L-carnitine treated sows had a higher feed intake during pregnancy ($P<0.05$) and higher plasma concentrations of insulin-like growth factor-1 (IGF-1) on day 80 of pregnancy than control sows ($P<0.05$). The number of piglets born was not different between the two groups of sows, but L-carnitine treated sows had fewer stillborn piglets ($P<0.05$). Piglets of L-carnitine treated sows had higher concentrations of L-carnitine in plasma and carcass at birth and on days 10 and 20 of age than control piglets ($P<0.05$). Chemical composition (concentrations of total lipids, protein and ash) of the carcass and plasma concentrations of IGF-1 and insulin, which are important modulators of growth, did not show any difference between the two groups of piglets at birth and on days 10 and 20. Concentrations of lipids (triacylglycerols, cholesterol) in liver and plasma and concentration free fatty acids in plasma were also broadly similar between the two groups of piglets at birth and on days 10 and 20. In conclusion, this study shows that supplementation of sows with L-carnitine improves the L-carnitine status of their piglets at birth and during the suckling period but does not influence their body composition or lipid metabolism.

Keywords: L-carnitine; sow; piglet; body composition; lipids; IGF-1; insulin

INTRODUCTION
Recent studies have demonstrated that supplementation of sows with L-carnitine during pregnancy increases body weights of piglets and litters at birth (Musser et al., 1999; Eder et al., 2001a; Ramanau et al., 2002). The biochemical mechanisms underlying this effect are largely unknown. Musser et al. (1999) observed increased plasma concentrations of insulin-like growth factor-1 (IGF-1) in sows supplemented with L-carnitine and suggested that this is responsible for higher birth weights of their progeny. IGF-1 plays an important role in the development of the placenta and the transport of nutrients across the placental barrier (Kelley et al., 1995; Sterle et al., 1995; Gluckman, 1997). An increased transplacental supply of the fetus with glucose leads to increased fetal insulin secretion, which might enhance the formation of lipids, i.e. triacylglycerols and cholesterol, through activation of sterol regulatory element binding proteins (SREBP)-1 and -2 in liver and adipose tissue (Shimano, 2001; Cagen et al., 2005; Yellaturu et al., 2005). Indeed, an increased plasma IGF-1 concentration in sows during the last three weeks of gestation induced by porcine growth hormone (pGH) treatment led to an increased percentage of total lipids in neonates (Kveragas et al., 1986). An increased transplacental supply of nutrients also leads to increased secretion of IGF-1 in the fetus (Gluckman, 1997). IGF-1, the main fetal growth promoting factor, enhances accretion of protein in particular. In contrast, insulin has a negligible effect on lean body mass but strongly enhances lipid synthesis (Gluckman, 1997). It has not yet been investigated whether L-carnitine supplementation of sows influences body composition, i.e. lipid accumulation, of their piglets relative to piglets of control sows.

Newborn piglets have a low capacity for endogenous formation of L-carnitine in their liver (Borum, 1983; Baltzell et al., 1987; Coffey et al., 1991). L-carnitine concentrations in blood and tissues of suckling piglets might therefore be influenced by the supply with L-carnitine through the milk. Due to its biological function (Bremer, 1961), a raised L-carnitine status could be associated with a higher rate of ß-oxidation of long chain fatty acids. In piglets and growing pigs L-carnitine supplementation has already been shown to increase the rate of ß-oxidation by increased activity of carnitine palmitoyltransferase I (CPT-1) and to reduce the content of total lipids in the whole body (Owen et al., 1996; Heo et al., 2000; Owen et al., 2001a, b). It has not yet been investigated whether raising the L-carnitine status of suckling piglets by supplementing their lactating mothers with L-carnitine influences their body composition (i.e. whole body lipid content).

The aim of this study was to find out whether changes in maternal IGF-1 concentrations through L-carnitine supplementation could lead to alterations of body composition and lipid metabolism in their piglets at birth and during the suckling period via altered concentrations of insulin and IGF-1. We therefore determined plasma IGF-1 in the sows in late pregnancy (day 80 and day 100 of pregnancy). As the availability of IGF-1 to target cells can be modified by IGF-binding proteins (IGFBP) (Thissen et al., 1994) we also determined plasma concentrations of IGFBP-3, the most important IGFBP in plasma of pigs (Owens et al., 1991). To show a possible relationship between the maternal L-carnitine status and that of newborn and suckling piglets, we also determined concentrations of L-carnitine in plasma and milk of sows and in plasma and carcass of piglets at birth and at 10 and 20 days of age. To study body composition and lipid metabolism of piglets, we determined the concentrations of major nutrients (fat, protein, ash) in the carcass and the concentrations of lipids (triacylglycerols, cholesterol) in liver and plasma as well as plasma concentrations of insulin and IGF-1, which are important modulators of lipid metabolism and body composition.

MATERIALS AND METHODS

Animals and housing

40 crossbred gilts (German Landrace x Large White) with an average body weight of 136 (± 9, SD) kg acquired from a local breeder were assigned to two groups of 20 animals each. Their sexual cycle was synchronized by oral administration of 20 mg Altrenogest per day (Regumate®, Hoechst Roussel Vet. N.V., Frankfurt, Germany). The sows were artificially inseminated with sperm from Pietrain boars. In the L-carnitine treated group, 19 of the 20 sows in the L-carnitine treated group conceived; in the control group, 16 of the 20 sows conceived. As only 30 single farrowing pens were available, only 15 of the 19 pregnant sows in the L-carnitine treated group, randomly selected, were considered for their reproductive performance. Two sows in the control group were removed before littering from the experiment because they had osteochondrosis in their knee joints. The sows were kept in single crates until day 30 of pregnancy. From day 30 to 110 of pregnancy the sows were kept in groups of six to eight in pens measuring 45 m^2 which had fully slatted floors, nipple drinkers and electronic feeding stations. On day 110 of pregnancy they were moved to the farrowing accommodation where they were housed in single farrowing pens. Prior to farrowing rubber mats were put down as lying surface for the piglets. An infrared heater was suspended above each rubber mat to keep the temperature for the newborn piglets at a constant 35°C. The climate in the dry sow accommodation and the farrowing unit was maintained at a temperature of 19 ± 2°C and 60-80% relative humidity by means of an air conditioning system. A light-dark cycle (12-hour light : 12-hour dark) was applied. All animal procedures described followed established guidelines for the care and handling of laboratory animals and were approved by the regional council of Saxony-Anhalt.

Diets and feeding

Two commercial sow diets were used whose composition and nutrient concentrations are shown in Table 1. The first diet ("gestation diet", SAL-SM-W4, Sächsische MUSKATOR-Werke GmbH, Riesa, Germany) was fed during pregnancy. Until day 110 of pregnancy, this diet was offered for ad libitum consumption. The daily feed intake of the sows was recorded by means of an electronic sow feeding station (Type IVOG 2FR VH, HokoFarm, Insentec B.V., Marknesse, The Netherlands). From day 110 to farrowing each sow was fed 2.5 kg of this diet per day. The second diet ("lactation diet", SL-INT 573, Sächsische MUSKATOR-Werke GmbH, Riesa, Germany) was fed during the lactation period. On the day of farrowing the sows were fed 1.5 kg of the diet, which was then successively increased (3 kg/d on day 1 and day 2 of lactation; 4.5 kg/day on day 3 and day 4 of lactation; ad libitum consumption from day 5 of lactation to weaning). Water was provided from nipple drinker systems throughout the whole feeding period.

Supplementation of L-carnitine

Supplementation of L-carnitine in the treatment group was started 21 days before insemination. Until insemination and throughout the entire pregnancy sows in the treatment group were supplemented with 125 mg L-carnitine per day. During lactation they were given 250 mg of L-carnitine per day. L-carnitine was supplied as tablets containing L-carnitine (62.5 mg/tablet), lactose and dextrose, supplied by Lohmann Animal Health (Cuxhaven, Germany). Each sow was given two tablets once daily in the morning (0900 h) by hand during pregnancy and two tablets

twice daily (0900, 1600 h) during lactation. The L-carnitine dosage was based on our recent studies (Ramanau et al., 2002; Ramanau et al., 2004). Control animals were given placebo tablets without L-carnitine.

Table 1: Composition of the diets used during pregnancy and lactation

	Gestation diet	Lactation diet
Ingredient (g/kg)		
Dried sugar beet pulp	300	-
Barley	225	263
Wheat	-	250
Wheat bran	217	-
Wheat meal	-	80
Wheat bran	-	80
Peas	-	80
Oat bran	70	-
Malt sprouts	69	-
Extracted sunflower meal	50	-
Wheat gluten feed	28	57
Extracted soybean meal	20	106
Vegetable oil	-	25
Alfalfa meal	-	15
Molasses	8.7	-
Calcium carbonate	4.4	11.3
Dried yeast	-	10
Sodium chloride	3.5	6
Monocalcium phosphate	-	1
Vitamin and mineral premix	2.5	11
L-lysine	1.9	4.3
DL-methionine		0.4
Nutrients		
Crude protein (g/kg)	138	173
Crude fibre (g/kg)	124	45
Crude ash (g/kg)	74	52
Crude fat (g/kg)	27	52
Lysine (g/kg)	6.4	9.9
Methionine (g/kg)	2.1	2.4
Threonine (g/kg)	4.6	5.7
Tryptophan (g/kg)	1.5	2.1
L-carnitine (mg/kg)	10	3
Metabolisable energy (MJ/kg)[a]	9.0	13.0

[a] Calculated according to recommendations by Gesellschaft für Ernährungsphysiologie (1987)

Standardisation of litter sizes

Five to six hours after birth one piglet with a body weight representing the mean of the whole group was selected, killed and used for analysis of its body composition. In order to eliminate the effect of litter size on body composition and metabolism, the litter size of all sows was then standardised to 8 piglets/litter within two days of farrowing. Sows with more than 8 piglets had the surplus piglets taken away and sows with less than 8 piglets were given piglets from other sows of the same group. Piglets removed from sows and piglets given to sows were selected on the basis of their body weights. The average weight of piglets from each individual sow after litter standardization was matched to that before litter standardization. Surplus piglets were nursed by one remaining sow in each group who was no longer included in the trial. Between day 3 and day 10 of the suckling period, four piglets of control sows and three piglets of sows supplemented with L-carnitine dropped out. These piglets were immediately replaced by equivalent piglets with similar body weights that had previously been nursed by the remaining control or L-carnitine treated sow. After 10 days another piglet from each litter representing the mean body weight of its litter mates

was selected and used for further analysis. This left 7 piglets in each litter. On day 20 a third piglet from each litter was selected and used for further analysis, reducing litter size to 6 piglets.

Data recording

Only sows whose litters were standardized were evaluated for body weights, number of piglets born, piglet and litter weights at birth and plasma L-carnitine concentrations. Sows were weighed (using scales with an accuracy of ± 100 g) on day 1 and day 110 of pregnancy. The number of piglets born (total, number born alive and number stillborn) was recorded. Individual piglets were weighed at birth (not later than 6 h after birth) and on days 10 and 20 of lactation using scales with an accuracy of ± 10 g.

Determination of nutrients and L-carnitine in carcasses and diets

The piglets were euthanized by bleeding. Blood of the piglets was collected for further analysis of plasma variables. Immediately after removal of the gastrointestinal tract caudal of the diaphragm and removal of liver, gallbladder, spleen and kidneys the carcass was frozen at -20°C. The organs cranial of the diaphragm remained in the carcass and were included in the analysis of the piglets' body composition. The carcasses were first cut with a saw (MADO Perekta Plus, MKB 649, Maschinenfabrik Dornhan, Germany), then finely chopped to a mushy consistency using a chopper (MADO Adjutant, MTK 661, Maschinenfabrik Dornhan, Germany) and finally homogenized for 3 minutes with a homogenizer (FOSS TECATOR, 2094 Homogenizer, Höganäs, Sweden). A representative sample of 500 g was drawn from the resulting carcass pulp, freeze-dried (CHRIST Beta 100800, MARTIN CHRIST, Osterode, Germany) and then finely ground in a water-cooled grinder (IKA-Universalmühle, M20, IKA Labortechnik Staufen, Germany) to a particle size of 1mm. The analysis of crude nutrient concentrations in the carcass (dry matter, crude protein, crude fat, crude ash) was performed in triplicate using an official German standard method (Bassler and Buchholz, 1993).

Concentrations of crude nutrients and amino acids in diets were analysed according to the same official German standard methods (Bassler and Buchholz, 1993). For the analysis of amino acids, samples were oxidized and then hydrolysed with 6 M hydrochloric acid. Separation and quantification of amino acids was performed by ion exchange chromatography following post-column derivatisation in an amino acid analyser (Biotronic LC 3000, Eppendorf, Hamburg, Germany). For the determination of tryptophan the diet was digested with barium hydroxide (Fontaine et al., 1998). The tryptophan content was determined by reversed-phase high performance liquid chromatography (Eder et al., 2001b). The concentration of total carnitine in plasma, carcass and diet was determined by a radiochemical method, which is based on the conversion of carnitine into [^{3}H]acetylcarnitine by carnitine-O-acetyltransferase (McGarry and Foster, 1976).

Collection of plasma and milk samples

On days 80 and 100 of pregnancy sows were bled 6 h after feeding by puncture of the fossa jugularis. Plasma was obtained by centrifugation of the blood (1,900 g, 10 min, 4^{o}C). Plasma lipoproteins were separated by step-wise ultracentrifugation (Mikro-Ultrazentrifuge, Sorvall Products, Bad Homburg, Germany) at 712.000 g at 4°C for 1.5 h (Tiedink and Katan 1989). Plasma densities were adjusted with sodium chloride and sodium bromide. The lipoprotein fractions [very low density lipoproteins (VLDL, δ<1.006 g/ml); low density lipoproteins (LDL, 1.006 g/ml<δ<1.063 g/ml) and high density lipoproteins (HDL, δ>1.063 g/ml)] were removed by suction. Five to eight hours after farrowing and on days 10 and 20 of lactation the sows were given 15 IU oxytocin (Atarost Tierarzneimittelfabrik, Twistringen, Germany) by intramuscular injection. 50 ml milk was expressed manually from all active teats of each sow.

Analysis of hormones and lipids

Concentrations of insulin, IGF-1 and IGFBP-3 in plasma were determined with commercial ELISA kits. Insulin was determined with a MEDGENIX INS-EASIA kit (Biosource Europe S. A., Nivelles, Belgium); intra- and interassay coefficients of variation (n=6) were 2.4% and 5.8%, respectively; the detection limit of the assay according to manufacturer instruction was 1.1 pmol/L. IGF-1 was determined with a OCTEIA®IGF-1-kit (Immunodiagnostic Systems, Boldon, United Kingdom). IGFBP-3 was determined with a ACTIVE®IGFBP-3 kit [Diagnostic Systems Laboratories (DSL) Inc., Webster, Texas, USA].

Lipids of the liver were extracted using a mixture of n-hexane and isopropanol (3:2, v/v) (Hara and Radin, 1978). Lipids of the extracts were dissolved in the aqueous phase of the test reagent with Triton X-100 (De Hoff et al., 1978). Concentrations of cholesterol and triglycerides were determined in plasma, LDL, HDL and liver lipid extracts using enzymatic reagent kits (Ecoline®DiaSys Diagnostics Sytems GmbH, Holzheim, Germany).

Statistical analysis

All statistics were carried out using SAS (2004). All dependent variables were analysed for normal distribution using the Shapiro-Wilk test. The effect of the treatment on body weights of piglets at birth was analysed with a mixed linear model (procedure mixed) which included the treatment (control vs. +L-carnitine) as a fixed effect and sows as random effects. All other normal distributed variables were analysed for significant differences by Student´s t-test. Non-parametric variables were evaluated for significant differences by Wilcoxon test. Means were considered significantly different for $P<0.05$.

RESULTS

Feed intake, body weights of sows, number and birth weights of piglets

Sows supplemented with L-carnitine had a higher feed intake during pregnancy and a higher body weight on day 110 of pregnancy than control sows (Table 2). The total number of piglets born and piglets born alive did not differ between control sows and sows supplemented with L-carnitine. But the number of stillborn piglets was lower in sows supplemented with L-carnitine than in control sows. Piglets and litters of sows supplemented with L-carnitine were 9 and 9%, respectively, heavier at birth than those of control sows. Differences in weights of piglets and litters were not statistically significant, however. The feed intake of the sows during lactation did not differ between the two groups.

Table 2: Body weights, feed intake, number of piglets and weights of piglets and litters in control sows and sows supplemented with L-carnitine[a]

	Control	+ L-carnitine	SEM
Body weights of sows, kg			
Day 1	135	137	1.65
Day 110	210[b]	219[c]	2.21
Feed intake, day 1-day 110, kg/d	3.3	3.7[c]	0.08
Feed intake, lactation, kg/day	5.2	5.3	0.10
Piglets born, n	11.4	10.6	0.41
Piglets born alive, n	10.5	10.4	0.39
Piglets stillborn, n	0.8[b]	0.1[c]	0.13
Weights of piglets at birth, kg	1.28	1.40	0.05
Weights of litters at birth, kg	13.2	14.4	0.43

[a] Means (n=13 for control, n=14 for + L-carnitine)
[b,c] Means with different superscript letters are significantly different ($P<0.05$)

Table 3: Concentrations of IGF-1 and IGF-binding protein 3 in plasma of control sows and sows supplemented with L-carnitine[a]

	Control	+ L-carnitine	SEM
IGF-1, nmol/L			
Day 80	3.9[b]	5.6[c]	0.40
IGF-binding protein 3, nmol/L			
Day 80	0.60[b]	0.52[c]	0.020
Day 100	0.55	0.47	0.026

[a] Means (n=13 for control, n=14 for + L-carnitine)
[b,c] Means with different superscript letters are significantly different ($P<0.05$)

Concentrations of IGF-1 and IGFBP-3 in sow plasma on days 80 and 100 of pregnancy

On day 80 of pregnancy sows supplemented with L-carnitine had higher concentrations of IGF-1 and lower concentrations of IGFBP-3 in plasma than control sows (Table 3). On day 100 of

pregnancy, a reliable determination of plasma concentrations of IGF-1 was not possible because in 7 of the 13 control sows and 7 of the 14 L-carnitine treated sows plasma IGF-1 concentration was below the detection limit of 1 nmol/L. Plasma concentration of IGFBP-3 on day 100 did not differ between sows treated with L-carnitine and control sows.

Concentrations of total L-carnitine in plasma and milk of sows

On day 80 of pregnancy, the concentration of total L-carnitine in plasma did not differ between both groups of sows (Table 4). In contrast, the plasma concentration of total L-carnitine on day 100 was significantly higher in sows supplemented with L-carnitine than in control sows. At birth, sows supplemented with L-carnitine moreover tended to have a higher concentration of total L-carnitine in milk than control sows ($P<0.10$). On days 10 and 20 of lactation, the concentration of L-carnitine in milk was significantly higher in sows supplemented with L-carnitine than in control sows.

Table 4: Concentrations of total L-carnitine in plasma and milk of control sows and sows supplemented with L-carnitine[a]

	Control	+ L-carnitine	SEM
Plasma, µmol/L			
Day 80	8.0	11.0	1.16
Day 100	8.8 [b]	14.9[c]	1.35
Milk, µmol/L			
Day 1 (colostrum)	183	221	11.4
Day 10	137[b]	212[c]	11.8
Day 20	126[b]	179[c]	8.4

[a] Means (n=13 for control, n=14 for + L-carnitine)
[b,c] Means with different superscript letters are significantly different ($P<0.05$)

Concentrations of total L-carnitine, IGF-1 and insulin in of piglets at birth and at 10 and 20 days of age

Piglets of sows supplemented with L-carnitine had higher concentrations of total L-carnitine in plasma and carcass at birth and on days 10 and 20 than piglets of control sows (Table 5). Plasma concentration of IGF-1 at birth could not be determined in a reliable way because in 8 of the 13 piglets of control sows and in 7 of the 14 piglets of L-carnitine treated sows it was below the detection limit of 1 nmol/L. Plasma concentrations of IGF-1 on days 10 and 20 as well as plasma concentrations of insulin, either at birth or on days 10 and 20 did not differ between both groups of piglets.

Table 5: Concentrations of total L-carnitine, IGF-1 and insulin in plasma of piglets of control sows and piglets of sows supplemented with L-carnitine at birth (day 1) and at days 10 and 20 of age[a]

	Control	+ L-carnitine	SEM
L-carnitine, µmol/L			
Day 1 (birth)	15.1[b]	20.0[c]	1.30
Day 10	15.6[b]	22.9[c]	1.73
Day 20	12.8[b]	17.5[c]	1.18
IGF-1, nmol/L[d]			
Day 10	5.4	6.4	0.57
Day 20	6.7	7.9	0.67
Insulin, pmol/L			
Day 1 (birth)	203	201	43.9
Day 10	89	78	12.7
Day 20	92	64	12.9

[a] Means (n=13 for control, n=14 for + L-carnitine)
[b,c] Means with different superscript letters are significantly different ($P<0.05$)
[d] IGF-1 concentrations at day 1 (birth) in 8 of the 13 piglets of control sows and in 7 of the 14 piglets of L-carnitine treated sows were below the detection limit of 1 nmol/L.

Body weights, chemical carcass composition and L-carnitine concentrations of piglets at birth and at 10 and 20 days of age

After litter standardization piglets of sows supplemented with L-carnitine did not differ in weight from those of control sows at birth or on days 10 and 20 of lactation (Table 6). Weights of carcasses of piglets of control sows and those of sows supplemented with L-carnitine did also not differ at birth or on days 10 and 20. Concentrations of protein and ash in carcass dry matter decreased continuously from birth to day 20 while the concentration of fat increased continuously. But the concentrations of these nutrients in the carcasses did not differ between piglets of control sows and those of L-carnitine supplemented sows at any time. Piglets of sows supplemented with L-carnitine had higher concentrations of total L-carnitine in carcass at birth and on days 10 and 20 than piglets of control sows (Table 6).

Table 6: Chemical composition and L-carnitine concentration of carcass of piglets of control sows and piglets of sows supplemented with L-carnitine at birth (day 1) and at days 10 and 20 of age[a]

	Control	+ L-carnitine	SEM
Day 1 (birth)			
Body weight (kg)	1.32	1.38	0.050
Carcass weight (kg)	1.09	1.11	0.040
Dry matter (DM) (g/kg)	189	187	2.1
Crude protein (g/kg DM)	565	576	4.7
Crude fat (g/kg DM)	57	52	1.8
Crude ash (g/kg DM)	220	221	2.6
L-carnitine (µmol/g DM)	0.94[b]	1.05[c]	0.030
Day 10			
Body weight (kg)	3.35	3.41	0.091
Carcass weight (kg)	2.78	2.86	0.077
Dry matter (DM) (g/kg)	301	291	3.3
Crude protein (g/kg DM)	469	471	5.6
Crude fat (g/kg DM)	409	391	7.2
Crude ash (g/kg DM)	104	111	2.3
L-carnitine (µmol/g DM)	1.32[b]	1.73[c]	0.055
Day 20			
Body weight (kg)	6.58	6.55	0.141
Carcass weight (kg)	5.60	5.58	0.126
Dry matter (DM) (g/kg)	345	345	3.0
Crude protein (g/kg DM)	415	420	4.0
Crude fat (g/kg DM)	438	442	5.2
Crude ash (g/kg DM)	90	85	1.7
L-carnitine (µmol/g DM)	1.39[b]	1.84[c]	0.062

[a] Means (n=13 for control, n=14 for + L-carnitine)
[b,c] Means with different superscript letters are significantly different (P<0.05)

Concentrations of lipids in plasma and liver of piglets at birth and at 10 and 20 days of age

Piglets of sows supplemented with L-carnitine had lower plasma concentrations of total cholesterol at birth than piglets of control sows (Table 7). On days 10 and 20 plasma concentrations of total cholesterol were not different between the two groups of piglets. Plasma triacylglycerols did not differ between the two groups of piglets at birth and on day 10. On day 20 plasma triacylglycerol concentration was higher in piglets of sows supplemented with L-carnitine than in piglets of control sows. Concentrations of triacylglycerols and total cholesterol in various lipoprotein fractions (VLDL, LDL, HDL) did not differ between both groups of piglets (data not shown) with the only exception of a reduced concentration of cholesterol in HDL in piglets of sows supplemented with L-carnitine compared to piglets of control sows (0.35 vs. 0.44 mmol/L, SEM=0.020 mmol/L, P<0.05). Plasma free fatty acids and hepatic concentrations of total cholesterol and triacylglycerols did not differ between the two groups of piglets at any time (Table 7).

Table 7: Concentrations of lipids in plasma and liver of piglets of control sows and piglets of sows supplemented with L-carnitine at birth (day 1) and at days 10 and 20 of age[a]

	Control	+ L-carnitine	SEM
Total cholesterol, plasma (mmol/L)			
Day 1 (birth)	1.25[b]	1.01[c]	0.053
Day 10	3.06	3.11	0.112
Day 20	4.58	5.04	0.157
Triacylglycerols, plasma (mmol/L)			
Day 1 (birth)	0.42	0.46	0.050
Day 10	0.82	0.95	0.057
Day 20	0.67[b]	0.88[c]	0.055
Free fatty acids, plasma (mmol/L)			
Day 1 (birth)	0.22	0.23	0.021
Day 10	0.36	0.43	0.043
Day 20	0.27	0.32	0.026
Total cholesterol, liver (µmol/g)			
Day 1 (birth)	6.51	5.92	0.433
Day 10	6.14	5.01	0.351
Day 20	7.59	8.17	0.288
Triacylglycerols, liver (µmol/g)			
Day 1 (birth)	17.8	16.9	1.39
Day 10	8.3	9.7	0.63
Day 20	12.3	12.5	0.33

[a] Means (n=13 for control, n=14 for + L-carnitine)
[b,c] Means with different superscript letters are significantly different (P<0.05)

DISCUSSION

In this study, sows were treated with L-carnitine during pregnancy and lactation. The finding that piglet and litter weights at birth did not differ between sows supplemented with L-carnitine and control sows disagrees with recent studies conducted with a large number of sows which showed that L-carnitine supplementation increases weights of litters and individual piglets significantly (Musser et al., 1999; Eder et al., 2001a; Ramanau et al., 2002). However, we are aware that the experiment presented due to the small number of sows is not suitable to study effects of L-carnitine on litter parameters at birth. The finding that L-carnitine supplemented sows had higher plasma IGF-1 concentrations on day 80 of pregnancy also agrees with the recent observation of Musser et al. (1999). These authors reported increased IGF-1 plasma concentrations in sows supplemented with L-carnitine on days 60 and 90 of pregnancy. A recent study (Waylan et al., 2005) did not find an effect of L-carnitine on plasma IGF-I concentrations in sows at day 28 and day 57 of pregnancy. The comparison of that study with our study and that of Musser et al. (1999) suggests that an effect of L-carnitine on plasma IGF-1 concentration might occur predominately after mid gestation. The biological action of IGFs can be modified by IGFBPs, which regulate their clearance from the circulation and modulate their bioavailability to target tissues (Thissen et al., 1994). The main circulating IGFBP in postnatal pigs is IGFBP-3 (Owens et al., 1991), which binds the IGFs and increases their half-life. Changes in the circulating concentration of IGFBP-3 may lead to changes in the concentration of free IGF-1 (Rehfeldt et al., 2004). The finding of a reduced plasma concentration of IGFBP-3 suggests that plasma IGF-1 in sows supplemented with L-carnitine might have been more available to target tissues than in control sows. In this study diets were fed ad-libitum and sows supplemented with L-carnitine had higher feed intakes than control sows. As an increased energy intake can raise plasma IGF-1 concentrations in sows (Rehfeldt et al., 2004) the possibility that the higher plasma concentrations of IGF-1 were caused by an increased feed intake cannot be ruled out. The finding that IGF-1 concentrations at day 100 are very low agrees with some other investigations which showed a clear decrease of plasma IGF-1 in sows at the late pregnancy (Armstromg et al., 1994; Musser et al., 1999). This is probably the result of a decreased stimulation of IGF-1 secretion by growth-hormone releasing factor and somatotropin (Armstrong et al., 1994). In the study of Waylan et al. (2005) plasma IGF-1 concentrations of control sows decreased from 15 nmol/L at day 0 of gestation to 7 nmol/L at day 28 and 2 nmol/L at day 57. In the study of Musser et al. (1999), plasma IGF-1 concentrations of control sows declined from 9 nmol/L at day 10 of gestation to 5 and 3 nmol/L at days 60 and 90, respectively. An IGF-1

concentration of 3.90 nmol/L in plasma of control sows at day 80 of pregnancy agrees well with the concentrations reported by Musser et al. (1999). The finding that plasma IGF-1 concentrations on day 100 were below 1 nmol/L in more than half of the sows shows that IGF-1 concentrations in pregnant sows are continuously declining until parturition. Because the detection limit of the assay used in our study was 1 nmol/L, we were not able to determine whether differences in plasma IGF-1 concentration between both groups of sows may also exist at day 100 of pregnancy.

The determination of L-carnitine concentrations in carcass and plasma of piglets shows that L-carnitine supplementation of sows improves the L-carnitine status of their newborn piglets. This effect might be due to an increased transfer of L-carnitine from the maternal blood to the fetuses as a result of the higher plasma L-carnitine concentrations in mothers supplemented with L-carnitine. The finding that the content of total lipids in carcass, concentrations of triacylglycerols and cholesterol in liver, plasma and lipoproteins and plasma concentrations of free fatty acids were not different between neonatal piglets of sows supplemented with L-carnitine and those of control sows suggests that L-carnitine supplementation of sows influences neither lipid biosynthesis nor lipolysis in the fetus close to term. This finding accords with the observation that the concentration of insulin which stimulates lipogenesis and inhibits lipolysis was not different between the two groups of piglets. The only change in lipid parameters observed in neonatal piglets of sows supplemented with L-carnitine compared with piglets of control sows was a reduced concentration of cholesterol in plasma and lipoproteins. This could be due to impaired secretion of cholesterol from the liver into the blood. But synthesis of cholesterol was probably not altered because the concentration of cholesterol in the liver did not differ between the two groups of piglets. The finding of very low plasma concentrations of IGF-1 in neonatal piglets agrees with observations of several other studies which have shown that plasma IGF-1 at birth are low and thereafter increase rapidly during the first 2 weeks of postnatal life as a result of the onset of growth-hormone stimulated IGF-1 production by the liver (Lee et al., 1991; Gluckman, 1995). Because plasma IGF-1 concentrations of more of the half of the piglets was below the detection limit of the IGF-1 assay used in this study, we were not able to detect potential differences in plasma IGF-1 concentration between both groups of piglets.

To eliminate the effects of litter size on the parameters investigated in the piglets, litters were standardized to an equal amount of piglets/litter. Because after birth and on days 10 and 20 of lactation, one piglet was removed from each litter for analysis of carcass composition, litter sizes being 8, 7, and 6 after birth and at days 10 and 20, respectively, were much lower than under practical condition. The litter size influences the milk production of the sow and its energy requirement (Etienne et al., 1998; Noblet et al., 1998). Because milk production does not increase proportionally to litter size, milk intake per piglet nursed increases when the litter size decreases. Milk intake per piglet for example increased from 0.7 to 1.0 kg/day when litter size decreased from 12 to 4 (Elsey, 1971) or from 0.9 to 1.3 kg/day when litter sizes decreased from 14 to 6 piglets/litter (Auldist et al., 1994). This means that piglets of the small litters in our study might have taken in more milk and might have grown faster than piglets of litters with normal sizes. Therefore, we cannot exclude the possibility that some effects would have been different if litter sizes would have been larger or not standardised. In recent studies, we (Eder et al., 2001, Ramanau et al., 2002, 2004) and others (Musser et al., 1999) observed that piglets of sows supplemented with L-carnitine grow faster during the suckling period than piglets of control sows. It has been shown that this effect is due to a higher milk production of sows supplemented with L-carnitine compared to control sows (Ramanau et al. 2004). The observation of the present study that piglets of sows supplemented with L-carnitine and those of control sows did not differ in their growth during the suckling period indeed could be due to the small litter sizes in this study.

The determination of the concentrations of L-carnitine in plasma and carcass of piglets at 10 and 20 days of age shows that suckling piglets of sows supplemented with L-carnitine have a better L-carnitine status than piglets of control sows. This might be due to the higher concentration of L-carnitine in the milk of sows supplemented with L-carnitine compared to milk of control sows. In a previous study with rats, it has been already shown that carnitine tissue concentrations during the early suckling period are strongly related to the carnitine concentration of the milk (Flores et al., 1996). L-carnitine is very important immediately after birth because it is required for generation of energy by ß-oxidation as the glucose supply is disrupted and glycogen stores are rapidly exhausted (Warshaw and Curry, 1980).

Under the experimental conditions used in this study, piglets of L-carnitine supplemented did not differ in chemical carcass composition (i.e. content of total lipids) and concentrations of lipids in liver, plasma and lipoproteins and plasma concentrations of free fatty acids on days 10 and

20 from piglets of control sows although they had a better L-carnitine status. The observation that plasma lipids were independent of the L-carnitine status of the piglets agrees with a previous study with piglets in which feeding of a formula diet with a low concentration of L-carnitine also did not influence the concentration of triacylglycerols in plasma (Coffey et al., 1991). The only change in lipid parameters observed in suckling piglets of sows supplemented with L-carnitine compared with piglets of control sows was an increased concentration of triacylglycerols in plasma on day 20 of age. This could be due to an increased secretion of triacylglycerols from the liver into the blood or a reduced degradation of triacylglycerol-rich lipoproteins by lipoprotein lipase. But synthesis of triacylglycerols was probably not altered because the concentration of triacylglycerols in the liver did not differ between the two groups of piglets.

In this study, we did not perform biochemical analyses of enzyme activities involved in lipid synthesis or ß-oxidation. It is, however, expected that biochemical alterations of the lipid metabolism should be associated with altered concentrations of lipids in tissues and plasma. Because the lipid contents in the carcasses of the piglets were completely unchanged and lipid parameters in plasma and liver were only negligibly different between both groups of piglets we suggest that the improved L-carnitine status of piglets of sows supplemented with L-carnitine was not associated with serious alterations of the lipid metabolism, i.e. ß-oxidation of fatty acids or synthesis of lipids. This suggestion disagrees with observations in weaned piglets and growing pigs where L-carnitine supplementation lowered the content of lipids in the whole body as a result of enhanced ß-oxidation of fatty acids (Owen et al., 1996; Heo et al., 2000; Owen et al., 2001b). The finding that body composition of piglets on days 10 and 20 did not differ between the two groups closely accords with the observation of unchanged plasma concentrations of insulin and IGF-1.

In conclusion, this study shows that L-carnitine supplementation of sows improves the L-carnitine status of their piglets at birth and during the suckling period but does not influence their body composition or concentrations of lipids in liver, plasma and lipoproteins. This shows that piglets of sows supplemented with L-carnitine do not differ in their lipid metabolism from piglets of control sows. It must be noted, however, that in this study piglets of sows supplemented with L-carnitine did not differ in their body weights at birth and during the suckling period from those of control sows which is in clear contradiction to recent studies (Musser et al., 1999, Eder et al., 2001, Ramanau et al., 2002, 2004). Therefore, the possibility that piglets of sows supplemented with L-carnitine would have differed in their body composition and lipid metabolism from piglets of control sows if they would have grown faster during suckling period than piglets of control sows as recently reported (Musser et al., 1999, Eder et al., 2001, Ramanau et al., 2002, 2004) cannot be excluded.

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Originalarbeit III

L-carnitine supplementation of sows during pregnancy improves the suckling behaviour of their offspring

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ABSTRACT
It has been shown that L-carnitine supplementation of sows increases their milk production and postnatal growth of the suckling piglets. To test the hypothesis that this effect is due to an improved suckling behaviour of their piglets, two experiments with sows were performed. Two groups of 13 or 10 sows each (in Experiments 1 and 2, respectively) were fed diets with or without supplemental L-carnitine during pregnancy (125 mg/d) and lactation (250 mg/d). After birth, litters of all sows were standardized to equal sizes of 11 and 9 piglets per litter in Experiments 1 and 2, respectively. In Experiment 1, piglets of L-carnitine supplemented sows had a higher total suckling time per day on days 3, 6 and 9 and heavier weight gains during suckling period than piglets of control sows ($P<0.05$). In Experiment 2, all litters were taken away from their mothers and switched to other sows. Half of the control sows and half of the L-carnitine supplemented sows were given litters born to control sows, the other half of each group was given litters born to L-carnitine supplemented sows. Piglets born to L-carnitine supplemented sows had a higher total suckling time per day on day 3 and heavier body weight gains during the first 14 days than piglets born to control sows ($P<0.05$). This study shows that piglets born to sows supplemented with L-carnitine are able to suckle for longer, which enables them to obtain more milk and grow faster than piglets born to control sows.

Keywords: L-carnitine; sow; piglet; suckling behaviour

INTRODUCTION
Several studies have shown that supplementing sows with L-carnitine during pregnancy and lactation increases their reproductive performance. Sows supplemented with L-carnitine had fewer stillborn piglets, more piglets born alive and heavier litter weights (Musser *et al.* 1999a, Eder *et al.* 2001, Ramanau *et al.* 2002, 2004, 2005). Moreover, it has been shown that litters of sows supplemented with L-carnitine gain more weight during the suckling period than litters of control sows (Musser et al. 1999a, Eder *et al.* 2001, Ramanau *et al.* 2002, 2004, 2005). Postnatal growth of piglets depends on their intake of energy and nutrients with the milk (Pluske & Dong 1998). Contents of energy and nutrients and the fatty acid composition of the milk do not differ between control sows and sows supplemented with L-carnitine (Ramanau *et al.* 2004, 2005). However, using the weigh-suckle-weigh method, we have shown that piglets of sows supplemented with L-carnitine are able to suckle more milk from the sow than piglets of control sows, which may explain their higher growth rates during the suckling period (Ramanau *et al.* 2004, 2005). The reason for the higher milk intake of piglets from sows supplemented with L-carnitine is unclear. Milk production of sows is strongly influenced by litter size, piglet weights and suckling intervals (King *et al.* 1997; Spinka *et al.* 1997, Auldist *et al.* 1998, 2000). If piglets suckle more frequently, with shorter intervals between sucklings, they will obtain more milk, thus causing milk production of the sow to rise. The hypothesis of the present study was that piglets of sows supplemented with L-carnitine are able to suckle more frequently or for longer periods due to an increased L-carnitine status, obtain more milk from the sow and therefore grow faster than piglets of control sows. To test this hypothesis, we performed two experiments with sows. In the first experiment, sows were assigned to a control group and a group supplemented with L-carnitine during pregnancy and lactation. After delivery litters were standardized to an identical size in order to avoid potential effects of differences in litter size on milk production and suckled from their mothers during a 28-day lactation period. The second experiment was performed to clarify whether alterations in the suckling behaviour of the piglets are due to pre- or postnatal effects of L-carnitine. In that experiment, sows were assigned to a control group and a group treated with L-carnitine. After delivery, all litters were taken away from their mothers and switched to other sows. Half of the control sows and half of the L-carnitine supplemented sows were given litters born to control sows, the other half of each group was given litters born to L-carnitine supplemented sows. If an improvement of the suckling behaviour is due to prenatal effects, litters born to sows supplemented with L-carnitine should have a higher suckling activity and grow faster during the suckling period than litters born to control sows, irrespective of whether they are suckled by control sows or by sows supplemented with L-carnitine. If the improved suckling behaviour of the piglets is due to postnatal effects of L-carnitine, litters suckled by sows supplemented with L-carnitine should have a higher suckling activity and gain more weight during the suckling period than litters suckled by

control sows, irrespective of whether they were born to control sows or to sows supplemented with L-carnitine.

MATERIALS AND METHODS

Animals and housing

All animal procedures described followed established guidelines for the care and handling of laboratory animals and were approved by the regional council of Saxony-Anhalt.

The first experiment was performed with 26 crossbred sows (German Landrace X Large White) in their second parity with a body weight of 179 (± 3, SE) kg. They were assigned to two groups, a control group and a group treated with L-carnitine, of 13 sows each. Twenty-four hours after weaning of their first litter the sows received 800 IU of pregnant mare serum gonadotropin (PMSG, Intergonan®6000, Intervet, Unterschleißheim, Germany) by intramuscular injection to stimulate oestrus. Seventy-two hours later they were injected with 500 IU human chorionic gonadotropin (hCG, Ovogest®5000, Intervet). Twenty-six hours after that they were artificially inseminated with sperm of Pietrain boars, followed by a second insemination 14 h later.

The second experiment was performed with 40 gilts (German Landrace X Large White) with a body weight of 143 (± 1, SE) kg. They were assigned to two groups, a control group and a group treated with L-carnitine, of 20 sows each. Their sexual cycle was blocked for 15 days by administration of Altrenogest (Regumate®, Hoechst Roussel Vet. N.V., Frankfurt, Germany). Twenty-four hours after the last dose of Regumate they were injected with 800 IU PMSG followed 80 h later by an injection of 500 IU hCG (Ovogest®5000, Intervet). Twenty-four hours after the hCG injection they were artificially inseminated with sperm of Pietrain boars, followed by a second injection 14 h later.

In the first experiment 9 of the 13 sows in the control group and all 13 sows in the L-carnitine treated group conceived. In the second experiment 13 of the 20 sows in the control group and 16 of the 20 sows in the L-carnitine treated group conceived. Farrowing was induced on day 115 of pregnancy by intramuscular injection of prostaglandin $F_{2\alpha}$ (Cloprostenol, Medistar GmbH, Holzwickede, Germany). Within two days after farrowing litter sizes of the sows to be considered during lactation were standardized to avoid potential effects of differences in litter size on milk production and weight gains of litters during the suckling period. In the first experiment litters of 8 randomly selected sows from each group were standardized to 11 piglets/litter.

In the second experiment litters of 10 sows from each group were standardized to 9 piglets per litter within two days of farrowing. Sows with more than 9 or 11 piglets, respectively, had the surplus piglets taken away and sows with less than 9 or 11 piglets were given piglets from other sows of the same group. Piglets removed from sows and piglets given to sows were selected on the basis of their body weights. The average weight of piglets of each sow after litter standardization was matched to that before litter standardization. Surplus piglets were nursed by the remaining sows of each group which were not considered for the purpose of the study. In the second experiment, all the litters were taken away from their mothers and switched to other sows. Litters of half of the control sows or L-carnitine treated sows, respectively, were switched to sows of the other experimental group and litters of the other half of each group were switched to different sows of the same treatment. This resulted in four combinations in the second experiment: (I) piglets born to control sows and suckled by different control sows; (II) piglets born to control sows and suckled by sows supplemented with L-carnitine; (III) piglets born to sows supplemented with L-carnitine and suckled by control sows; (IV) piglets born to sows supplemented with L-carnitine and suckled by different sows supplemented with L-carnitine.

The sows were kept in single crates until d 30 of pregnancy. From d 30 to 110 of pregnancy the sows were kept in groups of six to eight in pens measuring 45 m^2 which had fully slatted floors, nipple drinkers and electronic feeding stations. On d 110 of pregnancy they were moved to the farrowing accommodation where they were housed in single farrowing pens. Prior to farrowing rubber mats were put down as lying surface for the piglets. An infrared heater was suspended above each rubber mat to keep the temperature for the newborn piglets at a constant 35°C. Piglets were suckled for 28 days. The climate in the dry sow accommodation and the farrowing unit was maintained at a temperature of 19 ± 2°C and 60-80% relative humidity by means of an air conditioning system. A light-dark cycle (12-hour light:12-hour dark) was applied.

Diets and feeding

In both experiments two commercial sow diets were used whose composition and nutrient concentrations are shown in Table 1. The first diet ("gestation diet", DEUKA SF-SATT, Deuka, Könnern, Germany) was fed during pregnancy. Two different batches of this diet were used in Experiments 1 and 2, which varied slightly in their composition and nutrient concentrations.

Table 1: Composition of the diets used during pregnancy and lactation

	Gestation diet		Lactation diet
	Experiment 1	Experiment 2	Experiments 1, 2
Ingredient (g/kg)			
Dried sugar beet pulp	260	260	-
Barley	150	150	150
Wheat	-	-	344
Wheat bran	380	382	170
Extracted soybean meal	-	-	160
Extracted sunflower meal	110	140	-
Maize	-	-	80
Wheat gluten	33		
Triticale	25	30	
Soybeans	-	-	30
Vegetable oil	2	2	27
Molasses	25	20	-
Mineral premix	10	11	24
Premix containing vitamins and amino acids	5	5	15
Nutrients			
Crude protein (g/kg)	138	147	182
Crude fibre (g/kg)	120	135	48
Crude ash (g/kg)	59	61	46
Crude fat (g/kg)	30	30	59
L-carnitine (mg/kg)	7.4	6.5	2.5
Metabolisable energy (MJ/kg)[a]	9.0	8.7	12.6

[a] Calculated according to recommendations by Gesellschaft für Ernährungsphysiologie (1987)

Until day 30 of pregnancy each sow was fed 3.5 kg of gestation diet individually. From day 30 to day 110 of pregnancy, when the sows were kept in groups, they had free access to diets. The sows' daily feed intake was recorded by means of an electronic sow feeding station (Type IVOG 2FR VH, HokoFarm, Insentec B.V., Marknesse, The Netherlands). From day 110 of pregnancy to farrowing each sow was fed 2.5 kg of this diet per day. The second diet ("lactation diet", DEUKA LACTOSAN, Deuka) was fed during the lactation period. The same batches of this diet were used in Experiments 1 and 2. On the day of farrowing the sows were fed 1.5 kg of the diet, which was then successively increased (2 kg/day on day 1 and day 2 of lactation; 4 kg/day on days 3 to 7 of lactation; 5.5 kg/day from days 8 to 14; 6.0 kg/day from days 15 to 25). Thereafter the sows received 5.0 kg/day until weaning on day 28. Water was provided from nipple drinker systems throughout the whole feeding period.

Supplementation of L-carnitine

Sows in the treatment group were supplemented with 125 mg L-carnitine per day during pregnancy and 250 mg L-carnitine per day during lactation. L-carnitine was given as tablets containing L-carnitine (62.5 mg/tablet), lactose and dextrose, supplied by Lohmann Animal Health, Cuxhaven, Germany. The tablets were administered once daily in the morning (0900 h) by hand. During pregnancy each sow of the treatment group was given two tablets; during lactation each sow was given four tablets. Amounts of L-carnitine administered to the sows during pregnancy and lactation were selected according to our recent studies (Ramanau *et al.* 2002, Ramanau *et al.* 2004). Control animals were given the same tablets without L-carnitine.

Data recording

Body weights (using scales with an accuracy of ± 100 g) of the sows were recorded on days 1 and 105 of pregnancy and on the day of weaning. Individual piglets were weighed at birth (not later than 6 h after birth) and at 7, 14, 21 and 28 days of age using scales with an accuracy of ± 10 g. All the sows which conceived were evaluated for number of piglets born, piglet weights and litter weights at birth.

Determination of nutrients in the diets

Concentrations of crude nutrients in the diets were analysed according to the official German VDLUFA methodology (Bassler & Buchholz 1993). The metabolisable energy of the diet was calculated as recommended by the GfE (German nutrition society) (Gesellschaft für Ernährungsphysiologie 1987).

Analysis of L-carnitine in plasma, milk and diet

Piglets were bled by puncture of the venous plexus of the jugular fossa on day 1 (6 h post partum) and at 14 and 28 days of age. Plasma was obtained by centrifugation of the blood (1,100 g, 10 min, 4°C) and stored at -20°C pending analysis. On the day of birth and on day 11 of lactation the sows were given 15 IU oxytocin (Atarost GmbH&Co, Twistringen, Germany) by intramuscular injection and 80-100 mL milk was expressed manually from all active teats of each sow. Milk was stored at -20°C pending analysis.

The concentrations of total carnitine in plasma, milk and diet were determined by a radiochemical method, which is based on the conversion of carnitine to [^{3}H]acetylcarnitine by carnitine-O-acetyltransferase (McGarry & Foster 1976).

Determination of piglet suckling behaviour

In the first experiment 8 randomly selected sows from each group and their litters were filmed with a video camera (Time Lapse Cassette Recorder: Panasonic AG-6124-E, Matsushita Electric Ind. Co. Ltd., Osaka, Japan; camera: Visicom B/W-Kamera CCD-BW2012, MHM Electronic GmbH, Lindhorst, Germany) over a 24-h period on days 3, 6 and 9 of lactation. In the second experiment all the sows and their litters were filmed on day 3 of lactation. The video tapes were viewed with a video recorder (Video recorder: Panasonic AG 7350-E; monitor: Panasonic WV-CM 1430). The number of sucklings was counted and their mean duration and the total suckling time measured with a stop-watch. A suckling act was deemed to have occurred if the number of piglets nursing the udder was at least 60% of the sow's litter size (6 piglets/litter in exp. 1; 5 piglets/litter in exp. 2). The total suckling time per day was calculated as the sum of the individual nursing episodes. As lactation progresses the piglets' suckling behaviour changes; piglets more often tend to nose the udder individually and fall asleep there, making an accurate distinction between suckling and sleeping piglets extremely difficult or speculative. For this reason it was no longer possible to measure the suckling time after day 9 of lactation.

Statistical analysis

All statistics were carried out using SAS (2004). All dependent variables of the first experiment and dependent variables of pregnancy and litter performance of the second experiment were analysed with a mixed linear model (procedure mixed, version 8.2; SAS Institute Inc., Cary, N.C., USA) which included the treatment of sows (control sow vs. sow supplemented with L-carnitine) as a fixed effect. In the second experiment data of lactation were evaluated by using a mixed linear model (procedure mixed, version 8.2; SAS Institute Inc., Cary, N.C., USA) with treatment of sow (control sow vs. sow supplemented with L-carnitine), origin of the piglet (piglet of control sow vs. piglet of sow supplemented with L-carnitine) and their interaction as classification factors. Results are expressed as least square mean ± SEM. Means were considered significantly different for $P<0.05$.

RESULTS

Experiment 1: Feed intake and body weights of the sows during pregnancy and lactation, number and birth weights of piglets

Body weights on day 1 and day 108 and average daily feed intake during the entire pregnancy did not differ between the two groups of sows. Taking all pregnant sows in the experiment, values for control sows (n=9) and sows supplemented with L-carnitine (n=13) were:

body weight, day 1: 177 vs. 179 (SEM=3) kg; body weight, day 108: 248 vs. 242 (SEM=5) kg; daily feed intake: 3.4 vs. 3.4 (SEM=0.1) kg. Taking only the 8 sows from each group who were considered during lactation, there was again no difference in these parameters [control sows (n=8) vs. sows supplemented with L-carnitine (n=8): body weight, day 1: 176 vs. 181 (SEM=5) kg; body weight, day 108: 246 vs. 247 (SEM=6) kg; daily feed intake: 3.3 vs. 3.4 (SEM=0.1) kg]. Body weight at weaning and feed intake during lactation did also not differ between the two groups of sows [control sows (n=8) vs. sows supplemented with L-carnitine (n=8): body weight, weaning: 208 vs. 213 (SEM=7) kg; daily feed intake: 6.5 vs. 6.4 (SEM=0.04) kg].

Total litter size, number of piglets born alive and birth weights of piglets and litters did not differ between control sows and sows supplemented with L-carnitine. Values for control sows (n=9) and sows supplemented with L-carnitine (n=13) were: number of piglets born/litter: 11.2 vs. 12.4 (SEM=1.0); number of piglets born alive/litter: 11.1 vs. 12.3 (SEM=1.0); litter weight: 14.9 vs. 16.7 (SEM=1.2) kg; piglet weight: 1.37 vs. 1.38 (SEM=0.07) kg. However, the variation in body weights of piglets in a litter was lower in L-carnitine supplemented sows than in control sows (standard deviations of piglet weights in litters of control sows and litters of L-carnitine supplemented sows were 0.32 and 0.17 kg, respectively).

The sows which were considered during lactation also showed no differences in these parameters. Values for control sows (n=8) and sows supplemented with L-carnitine (n=8) were: number of piglets born/litter: 11.9 vs. 12.8 (SEM=1.0); number of piglets born alive/litter: 11.8 vs. 12.6 (SEM=1.0); litter weight: 15.6 vs. 17.5 (SEM=1.2) kg; piglet weight: 1.34 vs. 1.42 (SEM=0.09) kg.

Experiment 1: Suckling behaviour and weight gains of the piglets during the suckling period

The suckling behaviour of the piglets was studied at 3, 6 and 9 days of age. On all three days the number of sucklings per day was not different between piglets of control sows and those of sows supplemented with L-carnitine (Table 2). On days 3 and 6 the average duration of one suckling was however significantly higher in piglets of sows supplemented with L-carnitine than in piglets of control sows ($P<0.05$, Table 2). On day 9 the average duration of one suckling was marginally higher in piglets of sows supplemented with L-carnitine than in piglets of control sows ($P<0.10$, Table 2). The total suckling time per day was higher in piglets of sows supplemented with L-carnitine than in piglets of control sows on all three days ($P<0.05$, Table 2).

Average body weights of the piglets after standardization of litter sizes to 11 piglets/litter did not differ between piglets of control sows and those of sows supplemented with L-carnitine (Table 2). On days 7 and 28 body weights were heavier in piglets of sows supplemented with L-carnitine than in piglets of control sows ($P<0.05$, Table 2). On days 14 and 21 piglets of sows supplemented with L-carnitine were also slightly heavier than those of control sows but the differences were not significant ($P>0.05$, Table 2). The body weight gain between day 1 and day 28 was heavier in piglets of sows supplemented with L-carnitine than in control sows ($P<0.05$).

Experiment 2: Feed intake and body weights of the sows during pregnancy and lactation, number and birth weights of piglets

Body weights on day 1 and day 105 and average daily feed intake during the entire pregnancy did not differ between the two groups of sows. Taking all pregnant sows in the experiment, values for control sows (n=13) and sows supplemented with L-carnitine (n=16) were: body weight, day 1: 144 vs. 142 (SEM=2) kg; body weight, day 105: 206 vs. 204 (SEM=3) kg; daily feed intake: 3.0 vs. 3.1 (SEM=0.1) kg. Taking the 10 sows of each group which were considered during lactation, there was again no difference in these parameters [control sows (n=10) vs. sows supplemented with L-carnitine (n=10): weight, day 1: 143 vs. 141 (SEM=2) kg; body weight, day 105: 207 vs. 205 (SEM=4) kg; daily feed intake during pregnancy: 3.1 vs. 3.1 (SEM=0.1) kg]. Average daily feed intake during lactation and weights at weaning did not differ between control sows suckling piglets born to control sows (feed intake: 4.9 kg/d, SEM=0.3 kg/d; weight at weaning: 208 kg, SEM=7 kg), control sows suckling piglets born to sows supplemented with L-carnitine (feed intake: 4.8 kg/d, weight at weaning: 207 kg), sows supplemented with L-carnitine suckling piglets born to control sows (feed intake: 5.1 kg/d, weight at weaning: 207 kg) and sows supplemented with L-carnitine suckling piglets born to sows supplemented with L-carnitine (feed intake: 4.5 kg/d, weight at weaning: 203 kg).

Total litter size, number of piglets born alive and birth weights of piglets and litters did not differ between control sows and sows supplemented with L-carnitine. Taking all pregnant sows in the experiment, values for control sows (n=13) and sows supplemented with L-carnitine (n=16)

were: number of piglets born/litter: 10.9 vs. 10.9 (SEM=0.8); number of piglets born alive/litter: 10.8 vs. 10.6 (SEM=0.8); litter weight: 14.7 vs. 13.6 (SEM=0.9) kg; piglet weight: 1.38 vs. 1.32 (SEM=0.04) kg. The variation in body weights of piglets in a litter was similar in L-carnitine treated sows and in control sows (standard deviations of piglet weights in litters of control sows and litters of L-carnitine supplemented sows were 0.14 and 0.18 kg, respectively).

Taking the 10 sows of each group which were considered during lactation, there was again no difference in these parameters [control sows (n=10) vs. sows supplemented with L-carnitine (n=10): number of piglets born/litter: 10.3 vs. 10.9 (SEM=0.9); number of piglets born alive/litter: 10.2 vs. 10.4 (SEM=0.9); litter weight: 14.2 vs. 13.9 (SEM=0.9) kg; piglet weight: 1.41 vs. 1.36 (SEM=0.06) kg].

Table 2: Suckling behaviour (number of sucklings per day, average duration of one suckling and total suckling time per day) at days 3, 6 and 9 of age and body weights and weight gains of piglets of control sows and piglets of sows supplemented with L-carnitine (Experiment 1)

	Piglets of control sows	Piglets of sows supplemented with L-carnitine	SEM	P
Suckling behaviour	n=8	n=8		
Day 3				
Number of sucklings/day (n)	43.5	44.9	1.79	0.60
Average duration of one suckling (min)	4.73[a]	5.82[b]	0.30	0.02
Total suckling time/day (h)	3.45[a]	4.36[b]	0.28	0.04
Day 6				
Number of sucklings/day (n)	38.0	37.5	1.33	0.79
Average duration of one suckling (min)	3.27[a]	4.62[b]	0.40	0.03
Total suckling time/day (h)	2.07[a]	2.85[b]	0.22	0.03
Day 9				
Number of sucklings/day (n)	36.8	38.3	1.47	0.48
Average duration of one suckling(min)	4.19	5.01	0.30	0.07
Total suckling time/day (h)	2.56[a]	3.17[b]	0.18	0.03
Body weight (kg)	n=8	n=8		
Day 1 (birth)	1.40	1.48	0.07	0.44
Day 7	2.69[a]	3.00[b]	0.09	0.03
Day 14	4.71	5.12	0.18	0.13
Day 21	7.04	7.35	0.16	0.20
Day 28	9.14[a]	9.84[b]	0.21	0.03
Weight gain, day 1-28 (g/d)	274[a]	298[b]	8	0.05

Results are LS means. Means with unlike superscript letters (a, b) were significantly different (P<0.05)
[†]For details of diets and procedure see (p 5-10).

Experiment 2: Concentrations of free and total carnitine in the milk of the sows and plasma carnitine concentrations of piglets at birth and during the suckling period

Sows supplemented with L-carnitine had higher concentrations of total L-carnitine in colostrum [203 vs. 151 (SEM=15) µmol/L, P<0.05, n=10 for each group] and milk on day 7 [127 vs. 98 (SEM=9) µmol/L, P<0.05, n=10 for each group]. The concentration of free L-carnitine in the milk was relatively low and did not differ between milk from control sows and milk from L-carnitine supplemented sows [values in control sows vs. sows supplemented with L-carnitine: colostrum: 10.1 vs. 10.5 (SEM=1.2) µmol/L; milk on day 7: 44.4 vs. 43.1 (SEM=5.4) µmol/L].

At birth piglets born to sows supplemented with L-carnitine had higher concentrations of total carnitine in plasma than piglets born to control sows (P<0.05, Table 3). On day 14 plasma carnitine concentrations of piglets born to control sows and of piglets born to sows supplemented with L-carnitine were no longer different; but piglets suckled by sows supplemented with L-carnitine had higher plasma carnitine concentrations than those suckled by control sows (P<0.05, Table 3). On day 28 piglets born to sows supplemented with L-carnitine and suckled by sows supplemented with L-carnitine had the highest plasma carnitine concentrations and piglets born to control sows and also suckled by control sows had the lowest concentrations. Nevertheless, analysis of variance

showed that origin of the piglets and treatment of the sow during lactation did not influence plasma L-carnitine concentrations of piglets on day 28 (Table 3).

Table 3: L-carnitine concentrations in plasma of piglets born to control sows and piglets born to sows supplemented with L-carnitine, suckled either by control sows or by sows supplemented with L-carnitine, on days 1, 14 and 28 of age (Experiment 2)

Litter born to	Litter suckled by	n	Age of piglets		
			Day 1	Day 14	Day 28
			Total carnitine in plasma (µmol/L)		
Control sow	Control sow	5	12.3^{b}	12.1^{b}	7.7^{b}
Control sow	L-carnitine treated sow	5	14.2^{ab}	15.1^{ab}	10.3^{ab}
L-carnitine treated sow	Control sow	5	18.9^{ab}	10.7^{b}	10.4^{ab}
L-carnitine treated sow	L-carnitine treated sow	5	23.5^{a}	17.2^{a}	12.3^{a}
SEM			2.9	1.2	1.5
Litter born to					
Control sow		10	13.3^{b}	13.6	9.0
L-carnitine treated sow		10	21.2^{a}	13.9	11.4
SEM			2.1	0.8	1.1
Litter suckled by					
Control sow		10	15.6	11.4^{b}	9.1
L-carnitine treated sow		10	18.9	16.2^{a}	11.3
SEM			2.1	0.8	1.1
Results of ANOVA, P					
Origin of litter			0.02	0.80	0.13
Treatment of sow during lactation			0.28	0.001	0.15
Interaction			0.65	0.14	0.81

Results are LS means. Means with unlike superscript letters (a, b) were significantly different (P<0.05)
[†]For details of diets and procedure see (p 5-10).

Experiment 2: Suckling behaviour of the piglets and weight gains of the piglets during the suckling period

The number of sucklings per day at 3 days of age was not different between litters born to control sows and litters born to sows supplemented with L-carnitine (Table 4). There was also no difference in the number of sucklings between litters suckled by control sows and litters suckled by L-carnitine supplemented sows. But the average duration of one suckling was higher in litters born to sows supplemented with L-carnitine than in litters born to control sows (P<0.05, Table 4). The total suckling time per day was also higher in litters from sows supplemented with L-carnitine than in litters from control sows (P<0.05, Table 4). Litters suckled by control sows and litters suckled by sows supplemented with L-carnitine did not differ in the average duration of one suckling and the total suckling time per day.

At birth piglets born to control sows and those born to sows supplemented with L-carnitine did not differ in their weights [1.40 vs. 1.36 (SE=0.05) kg]. Body weight gains between birth and day 7 and body weight gains between day 7 and day 14 were heavier in piglets born to sows supplemented with L-carnitine than in piglets born to control sows (P<0.05), irrespective of whether they were suckled by control sows or by sows supplemented with L-carnitine (Table 5). Body weights on day 14 were also significantly heavier in piglets born to sows supplemented with L-carnitine than in piglets born to control sows [4.67 vs. 4.32 (SE=0.12) kg, P<0.05]. Body weight gains between day 14 and day 21 and between day 21 and day 28 did not differ between piglets born to control sows and those born to sows supplemented with L-carnitine (Table 5). Weight gain during the entire suckling period (birth – day 28) was not different between piglets born to control sows and those born to sows supplemented with L-carnitine (Table 5). Body weights on day 28 did not differ between piglets born to sows supplemented with L-carnitine and piglets born to control sows [8.88 vs. 8.50 (SE=0.23) kg, P>0.05]. Litters suckled by sows supplemented with L-carnitine

did not differ in their weight gains from litters suckled by control sows during the entire suckling period (Table 5).

Table 4: Suckling behaviour (number of sucklings per day, average duration of one suckling and total suckling time per day) of piglets born to control sows and piglets born to sows supplemented with L-carnitine, suckled either by control sows or by sows supplemented with L-carnitine, at day 3 of age (Experiment 2)

Litter born to	Litter suckled by	n	Number of sucklings/ day (n)	Average duration of one suckling (min)	Total suckling time per day (h)
Control sow	Control sow	5	43.6	3.7^{b}	2.7^{a}
Control sow	L-carnitine treated sow	5	45.1	3.7^{b}	2.8^{ab}
L-carnitine treated sow	Control sow	5	43.3	4.2^{a}	3.0^{ab}
L-carnitine treated sow	L-carnitine treated sow	5	44.3	4.3^{a}	3.2^{b}
SEM			0.9	0.2	0.2
Litter born to					
Control sow		10	44.4	3.7^{b}	2.7^{b}
L-carnitine treated sow		10	43.8	4.2^{a}	3.1^{a}
SEM			0.6	0.1	0.1
Litter suckled by					
Control sow		10	43.4	3.9	2.8
L-carnitine treated sow		10	44.7	4.0	3.0
SEM			0.6	0.1	0.1
Results of ANOVA, P					
Origin of litter			0.51	0.01	0.02
Treatment of sow during lactation			0.15	0.56	0.23
Interaction			0.80	0.71	0.79

Results are LS means. Means with unlike superscript letters (a, b) were significantly different ($P<0.05$)
[†]For details of diets and procedure see (p 5-10).

DISCUSSION

In this study sows were supplemented with L-carnitine during pregnancy and lactation. In both experiments L-carnitine supplementation of sows did not increase weights of litters or of individual piglets at birth. This is in disagreement with recent studies which demonstrated in large groups of sows that L-carnitine supplementation significantly increases weights of litters and of individual piglets (Musser *et al.* 1999a, Eder *et al.* 2001, Ramanau *et al.* 2002). We are aware that because of the small number of sows used, the experiments presented here are not suitable to study effects of L-carnitine on litter parameters at birth. Interestingly, in both experiments, more sows conceived in the L-carnitine group than in the control group. This finding agrees with results of a recent study which considered also a small number of sows (Birkenfeld *et al.* 2006), suggesting that L-carnitine supplementation could improve the pregnancy rate of sows. However, no study with a larger number of sows has been performed which shows a beneficial effect of L-carnitine supplementation on the pregnancy rate.

In the first experiment of this study piglets of sows supplemented with L-carnitine had heavier body weight gains during the 28-day suckling period than piglets of control sows. This finding agrees with our recent studies (Eder *et al.* 2001, Ramanau *et al.* 2002, 2004, 2005). Moreover, the first experiment demonstrates that piglets of sows supplemented with L-carnitine are able to suckle for a longer time per day at 3, 6, and 9 days of age than piglets of control sows.

The second experiment was designed to find out whether beneficial effects of L-carnitine supplementation of sows on the suckling behaviour and growth of the piglets during the suckling period are induced during the pre- or the postnatal phase of the piglets. We observed that piglets born to sows supplemented with L-carnitine are able to suckle for longer on day 3 and grow faster

during the first 14 days of the suckling period than piglets born to control sows, irrespective of whether they were suckled by control sows or by sows supplemented with L-carnitine. This observation demonstrates that effects of L-carnitine supplementation during pregnancy were responsible for higher postnatal growth of the piglets and that L-carnitine supplementation of lactating sow does not influence the growth of the suckling piglets.

Table 5: Weight gains of piglets born to control sows and piglets born to sows supplemented with L-carnitine, suckled either by control sows or by sows supplemented with L-carnitine (Exp. 2)

Litter born to	Litter suckled by	n	Time interval				
			Day 1-7	Day 7-14	Day 14-21	Day 21-28	Day 1-28
			Body weight gain (g/d)				
Control sow	Control sow	5	164^{b}	237^{b}	263	322	246
Control sow	L-carnitine treated sow	5	175^{ab}	256^{ab}	290	320	260
L-carnitine treated sow	Control sow	5	189^{ab}	292^{a}	254	327	266
L-carnitine treated sow	L-carnitine treated sow	5	191^{a}	274^{ab}	292	329	271
SEM			9	18	19	22	11
Litter born to							
Control sow		10	170^{b}	246^{b}	277	321	253
L-carnitine treated sow		10	190^{a}	283^{a}	273	328	269
SEM			6	13	13	16	8
Litter suckled by							
Control sow		10	177	265	259	325	256
L-carnitine treated sow		10	183	265	291	325	266
SEM			6	13	13	16	8
Results of ANOVA, P							
Origin of litter			0.04	0.04	0.85	0.74	0.19
Treatment of sow during lactation			0.48	0.98	0.10	0.99	0.38
Interaction			0.22	0.31	0.79	0.93	0.71

Results are LS means. Means with unlike superscript letters (a, b) were significantly different (P<0.05)
[†]For details of diets and procedure see (p 5-10).

It has been shown that sows exposed to increased suckling demand, i.e. by nursing heavier piglets or nursing piglets more frequently, produce more milk (King *et al.* 1997, Auldist *et al.* 2000). More prolonged suckling by the piglets may have imposed greater suckling demand on the sow, which in turn may have the stimulated milk production of the sow. We observed recently that piglets of sows supplemented with L-carnitine are able to obtain more milk from the sow than piglets of control sows (Ramanau *et al.* 2004, 2005). The present study shows that this effect is due to increased suckling activity by piglets born to sows supplemented with L-carnitine. The higher milk intake of the piglets due to increased suckling activity explains their higher growth rates during the suckling period. We were unable for technical reasons to study the suckling behaviour of the piglets after day 9. As piglets of sows supplemented with L-carnitine tended to have higher growth rates than piglets of control sows, even in the last week of the suckling period, we assume that piglets of those litters had a more favourable suckling behaviour and a higher milk intake than piglets of control sows also after day 9. It has been shown that energy and nutrient contents and the fatty acid composition in the milk do not differ between sows supplemented with L-carnitine and control sows (Ramanau *et al.* 2004, 2005). Milk composition might therefore not play a role as regards differences in growth rates between piglets of control sows and piglets of sows supplemented with L-carnitine. It cannot be ruled out that piglets of sows supplemented with L-carnitine not only suckled for a longer time per day but also with more vigour than piglets of control sows. But this hypothesis could not be tested in this study.

The finding that piglets suckled by control sows do not differ in body weight gains from piglets suckled by sows supplemented with L-carnitine demonstrates that L-carnitine supplementation did not influence the milk yield of the sow. It has been shown that the size and the

milk yield of the mammary gland increases with increasing number of fetuses. This has been linked to a greater placental lactogen level (Forsyth 1986, Forsyth & Wallis 2002). In a recent study, sows supplemented with L-carnitine had a significantly higher number of newborn piglets than control sows (Ramanau et al. 2004). The increased number of piglets could have led to increased placental lactogen levels which in turn could have led to increased mammary gland sizes which may have contributed to the increased milk yield observed in the sows supplemented with L-carnitine in that study. In the present study, L-carnitine supplementation did not influence the number of piglets in both experiments and probably did not influence the release of placental lactogen and the development of the mammary gland. This matches with the finding that L-carnitine supplementation did not influence milk yield of the sows.

The present study shows that L-carnitine supplementation during lactation does not influence the suckling behaviour of the piglets and their growth during the suckling period. This observation agrees with results of Musser *et al.* (1999a, 1999b) who studied the effects of L-carnitine supplementation during pregnancy and during lactation separately. These authors showed that L-carnitine supplementation of sows during pregnancy increases litter weight gains during the suckling period while L-carnitine supplementation during lactation alone does not. There was some disagreement between the two experiments in that piglets born to sows supplemented with L-carnitine in the first experiment showed higher body weight gains during the entire 28-day suckling period while in the second experiment they had higher body weight gains than piglets of control sows only during the first 14 days. This discrepancy can have several reasons as the experimental conditions were not identical in the two experiments. Nevertheless, data from both experiments show that L-carnitine supplementation of sows during gestation increases weight gains of their litters during the suckling period, regardless of whether or not the sows received L-carnitine during lactation.

The reason for the increased suckling activity observed in piglets born to sows supplemented with L-carnitine is unclear. As piglets of sows supplemented with L-carnitine did not differ from those of control sows in their initial body weights and as litters were standardized to an identical number of piglets, the possibility that differences in litter sizes or piglet weights could play a role in influencing suckling behaviour and postnatal growth rates can be ruled out. It could be that the improved L-carnitine status at birth, as assessed by higher plasma L-carnitine concentrations, increased the suckling activity of piglets from sows supplemented with L-carnitine. Immediately after birth L-carnitine plays an important role in energy production. During the intrauterine phase the supply of the fetus with amino acids, glucose, minerals and fatty acids from the mother via the placenta is essential for its development. The rate of fatty acid oxidation in the fetus is low (Novak *et al.* 1981). However, immediately after birth oxidation of fatty acids becomes important because of the discontinuation in the glucose supply and the rapid exhaustion of glycogen stores (Warshaw & Curry, 1980). Sufficient concentrations of L-carnitine in tissues are required for the utilisation of fatty acids for energy production. L-carnitine is required for both, the release of fatty acids from adipose tissue and fatty acid utilisation (Hahn, 1982; Novak *et al.*, 1975a, 1975b). We suspect that piglets of sows supplemented with L-carnitine were able to switch on fatty acid oxidation faster than piglets of control sows. Greater fatty acid oxidation leads to increased energy and heat production by piglets, which in turn might have increased their suckling persistence during the first few days after birth.

However, the L-carnitine status alone cannot explain the differences in suckling behaviour and in body weight gains between piglets born to sows supplemented with L-carnitine and those born to control sows. If L-carnitine status alone had been responsible for suckling behaviour and growth during the suckling period, piglets suckled by sows treated with L-carnitine would have grown faster than piglets suckled by control sows at least after the second week because they had higher plasma L-carnitine concentrations on day 14 than piglets suckled by control sows. Yet weight gains of litters were not different between piglets suckled by sows supplemented with L-carnitine and those suckled by control sows. Musser *et al.* (1999a) suggested that L-carnitine supplementation of sows increases the intrauterine nutrition of the fetuses and their development. These authors also showed that piglets born to sows supplemented with L-carnitine have more muscle fibres, a greater loin depth, a higher percentage of lean and less backfat than piglets of control sows, which might be due to higher maternal plasma concentrations of insulin-like growth factor-1 (Musser *et al.* 2000, 2001). It is conceivable that improved fetal development due to supplementation of their mothers with L-carnitine could have led to increased piglet vitality at birth, which might have been associated with increased suckling persistence. This suggestion remains speculative however because we did not measure parameters of piglet vitality.

It is known that the endogenous synthesis of carnitine is extremely low in the fetus and during the first week of life and increases thereafter (Borum 1981, Baltzell *et al.* 1987, Coffey *et al.* 1991). Higher plasma L-carnitine concentrations at birth observed in piglets born to sows supplemented with L-carnitine might be due to an increased transplacental supply of L-carnitine to the fetuses. It was shown previously that supplementation of sows with L-carnitine increases their plasma L-carnitine concentrations (Musser et al. 1999a, Ramanau *et al.* 2004, 2005). As L-carnitine can cross the placenta, increased maternal plasma L-carnitine concentrations may lead to higher fetal plasma carnitine concentrations (Lahjouji *et al.* 2004, Grube *et al.* 2005). Higher plasma carnitine concentrations on day 14 in piglets suckled by sows supplemented with L-carnitine compared with piglets suckled by control sows might be due to a higher L-carnitine intake with the milk. The finding that milk of sows supplemented with L-carnitine contains more L-carnitine than milk of control sows agrees with recent studies (Ramanau *et al.*, 2004, 2005). Interestingly, plasma L-carnitine concentrations on day 28 were no longer different between piglets suckled by sows supplemented with L-carnitine and piglets suckled by control sows.

In conclusion, this study shows that piglets born to sows supplemented with L-carnitine are able to suckle for longer in the early suckling period, obtain more milk and grow faster during the first 14 days than piglets born to control sows. It has also been shown that this effect is due to supplementation of L-carnitine of the sows during gestation. The practical implication of this study is that L-carnitine must be administered to sows during gestation to obtain beneficial effects on the growth of their litters during the suckling period.

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Originalarbeit IV

Nutrient composition and concentrations of immunoglobulines in milk of sows supplemented with L-carnitine

RESEARCH NOTE

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ABSTRACT
Recent studies have shown that L-carnitine supplementation of sows increases growth of their piglets during the suckling period. In this study, the composition of the milk of sows supplemented with L-carnitine was determined to find out whether an altered milk composition could account for the increased growth rates of the piglets. Milk of 13 control sows and 14 sows supplemented with L-carnitine (125 mg/d during pregnancy, 250 mg/d during lactation) was collected 5-8 hours after birth (colostrum) and on days 10 and 20 of lactation. Concentrations of fat and lactose and the energy content did not differ between both groups of sows in milk of days 10 and 20. Sows supplemented with L-carnitine had a higher concentration of protein in colostrum ($p < 0.05$) while concentrations of fat, lactose, immunoglobulines G, M and A as well as the energy content in colostrum did not differ between both groups of sows. These findings show that milk composition does not play a major role for the increased postnatal growth of piglets from sows supplemented with L-carnitine observed in recent studies.

Keywords: Sow, piglet, milk, colostrum, L-carnitine

INTRODUCTION
Recent studies have shown that supplementation of L-carnitine in sows improves their reproductive performance (Musser et al. 1999, Eder et al. 2001, Ramanau et al. 2002). Sows supplemented with L-carnitine during pregnancy had higher litter weights and piglet weights at birth than control sows (Musser et al. 1999, Eder et al. 2001, Ramanau et al. 2002). Moreover, piglets of sows supplemented with L-carnitine were growing faster during the suckling period and had higher body weights at weaning than piglets of control sows (Musser et al. 1999, Eder et al. 2001, Ramanau et al. 2002, 2004, 2005). The growth during the suckling periods depends on the piglets´ intake of energy and nutrients from sows´ milk (Pluske & Dong 1998). We have recently shown that sows supplemented with L-carnitine during pregnancy and lactation are able to produce more milk than control sows (Ramanau et al. 2004). The increased intake of nutrients of piglets which leads to higher postnatal growth rates could be due, besides an increased amount of milk, also to an altered composition of the milk, i.e. increased concentrations of nutrients and energy. In a recent study, milk composition at day 11 of lactation was not different between sows supplemented with L-carnitine and those of control sows (Ramanau et al. 2004). However, it cannot be excluded that milk composition could have been influenced by L-carnitine supplementation in an earlier stage of lactation. For survival and growth during the first days of life, the colostrum plays an important role. Colostrum is not only rich in nutrients highly digestible for the piglet but contains high concentrations of immunoglobulines for the passive immunisation of the piglet. The neonatal piglet is born with a very low immunological status and depends on the ingestion and absorption of colostral immunoglobulins for passive antibody immunity (Aumaitre & Seve 1978, Darragh & Moughan 1998).

In growing pigs, L-carnitine supplementation enhanced ß-oxidation of fatty acids and lowered oxidation of amino acids which in turn led to an increased rate of protein synthesis (Heo et al. 2000, Owen et al. 2001a, b). Whether L-carnitine supplementation in sows alters the composition of the colostrum, i.e. concentrations of immunoglobulines, has not yet been investigated.

Therefore, in this study we investigated the effect of L-carnitine on the composition of the milk, including concentrations of immunoglobulines in the colostrum. For this purpose, we used sows which have been recently used to investigate the effect of L-carnitine on body composition and concentrations of lipids in liver and plasma of their piglets (Birkenfeld et al. 2006a). From these sows, we collected milk samples 5-8 hours after birth and at days 10 and 20 of lactation, and determined the concentrations of protein, fat and lactose in these samples, and in colostrum additionally the concentrations of the main immunoglobulines.

Recently, we found that piglets born from sows supplemented with L-carnitine are able to suckle for a longer time than piglets of control sows (Birkenfeld et al., 2006b) which may explain their higher milk intake, recently observed (Ramanau et al. 2004, 2005). In this study, we took the opportunity to determine the suckling behaviour of the piglets in the early suckling period to confirm the recent observation.

MATERIAL AND METHODS

Animals, diets and L-carnitine supplementation

This experiment was conducted with 27 pregnant gilts (German Landrace x Large White, 13 control sows, 14 L-carnitine treated sows) which have been already used in a previous study (Birkenfeld *et al.* 2006a). Control sows and L-carnitine treated sows had an initial body weight of 135 and 137 kg, respectively. They were kept in single crates until day 30 of pregnancy. From day 30 to 110 of pregnancy, they were kept in groups of six to eight in pens measuring 45 m^2 which had fully slatted floor, nipple drinkers and electronic feeding stations. On day 110 of pregnancy they were moved to the farrowing accommodation where they were housed in single farrowing pens. According to the experimental design to investigate the effect of L-carnitine supplementation on body composition (Birkenfeld *et al.* 2006a), five to six hours after birth one piglet was removed from each litter for analysis. Thereafter, the litter size of all sows was then standardised to 8 piglets per litter within two days of farrowing. During the lactation period, piglets did not receive any other feed. All animal procedures described followed established guidelines for the care and handling of laboratory animals and were approved by the regional council of Saxony-Anhalt.

Two commercial sow diets were used whose compositions are shown in Table I. The first diet ("gestation diet", SAL-SM-W4, Sächsische MUSKATOR-Werke GmbH, Riesa, Germany) was fed during pregnancy. Until day 110 of pregnancy, this diet was offered for ad libitum consumption. From day 110 to farrowing each sow was fed 2.5 kg of this diet per day. The second diet ("lactation diet", SL-INT 573, Sächsische MUSKATOR-Werke GmbH, Riesa, Germany) was fed during the lactation period. On the day of farrowing the sows were fed 1.5 kg of the diet, which was then successively increased (3 kg/day on day 1 and day 2 of lactation; 4.5 kg/day on day 3 and day 4 of lactation; ad libitum consumption from day 5 of lactation to weaning). Water was provided from nipple drinker systems throughout the whole feeding period.

Supplementation of L-carnitine in the treatment group was started 21 days before insemination. Until insemination and throughout the entire pregnancy sows in the treatment group were supplemented with 125 mg L-carnitine per day. During lactation they were given 250 mg of L-carnitine per day. L-carnitine was supplied as tablets containing L-carnitine (62.5 mg/tablet), lactose and dextrose, supplied by Lohmann Animal Health (Cuxhaven, Germany). Each sow was given two tablets once daily in the morning (0900 h) by hand during pregnancy and two tablets twice daily (0900, 1600 h) during lactation. More details about animals and diets are shown in Birkenfeld *et al.* (2006).

Determination of piglet suckling behaviour

Ten randomly selected sows from each group and their litters were filmed with a video camera (Time Lapse Cassette Recorder: Panasonic AG-6124-E, Matsushita Electric Ind. Co. Ltd., Osaka, Japan; camera: Visicom B/W-Kamera CCD-BW2012, MHM Electronic GmbH, Lindhorst, Germany) over a 24-h period on day 3 of lactation. The video tapes were viewed with a video recorder (Video recorder: Panasonic AG 7350-E; monitor: Panasonic WV-CM 1430). The number of sucklings was counted and the average time of one suckling as well as the average time between two sucklings was measured with a stop-watch. A suckling act was deemed to have occurred if the number of piglets nursing the udder was at least 60% of the sow's litter size (5 of 8 piglets). The total suckling time per day was calculated as the sum of the individual nursing episodes.

Analysis of milk constituents

Five to 8 hours after birth and on days 10 and 20 of lactation, the sows were given 15 IU oxytocin (Atarost GmbH&Co, Twistringen, Germany) by intramuscular injection. 80-100 mL milk was expressed manually from all active teats of each sow. The concentration of lactose in the milk was determined using an enzymatic kit reagent from Boehringer (Mannheim, Germany, Cat-No. 0176303); the concentration of protein in the milk was determined by the kjehldahl method by the IDF-ISO-AOAC method (AOAC 1999); the concentration of fat in the milk was determined by the ether extraction method (AOAC 1999). The concentrations of immunoglobulines (IgG, IgA, IgM) in the colostrum was determined by using an ELISA for quantitative determination of immunoglobulines in pigs (Celltrend GmbH, Luckenwalde, Germany, Cat-No. IgG: 53100, IgA 53200, IgM: 53300). The energy content of the milk was calculated from the concentrations of protein, fat and lactose; the following energy contents were used: lactose, 16.4 kJ/g; fat, 39.4 kJ/g; protein, 23.5 kJ/g (National Research Council 1998).

Table I: Composition of the diets used during pregnancy and lactation

	Gestation diet	Lactation diet
Ingredient (g/kg)		
Dried sugar beet pulp	300	-
Barley	225	263
Wheat	-	250
Wheat bran	217	-
Wheat meal	-	80
Wheat bran	-	80
Peas	-	80
Oat bran	70	-
Malt sprouts	69	-
Extracted sunflower meal	50	-
Wheat gluten feed	28	57
Extracted soybean meal	20	106
Vegetable oil	-	25
Alfalfa meal	-	15
Molasses	8.7	-
Calcium carbonate	4.4	11.3
Dried yeast	-	10
Sodium chloride	3.5	6
Monocalcium phosphate	-	1
Vitamin and mineral premix	2.5	11
L-lysine	1.9	4.3
DL-methionine		0.4
Nutrients		
Crude protein (g/kg)	138	173
Crude fibre (g/kg)	124	45
Crude ash (g/kg)	74	52
Crude fat (g/kg)	27	52
Lysine (g/kg)	6.4	9.9
Methionine (g/kg)	2.1	2.4
Threonine (g/kg)	4.6	5.7
Tryptophan (g/kg)	1.5	2.1
L-carnitine (mg/kg)	10	3
Metabolisable energy (MJ/kg)[1]	9.0	13.0

[1] Calculated according to recommendations by Gesellschaft für Ernährungsphysiologie (1987)

Statistical analysis

All statistics were carried out using SAS (2004). All variables were normal distributed as examined by the Shapiro-Wilk test. Means of the two groups were analysed for significant differences by Student´s *t*-test. Means were considered significantly different for $P<0.05$.

RESULTS

Feed intake, body weights of sows, litter sizes and weights of litters and piglets at birth

Sows supplemented with L-carnitine had a higher feed intake during pregnancy (3.7 ± 0.1 vs. 3.3 ± 0.1 kg/day, means ± SE, P=0.04, n=13 for control group, n=14 for L-carnitine treated group) and a higher body weight on day 110 of pregnancy pregnancy (219 ± 3 vs. 210 ± 3 kg, P=0.04) than control sows. The total number of piglets born and piglets born alive did not differ between control sows and sows supplemented with L-carnitine (values in control sows vs. L-carnitine supplemented sows: piglets born per litter: 11.4 ± 0.6 vs. 10.6 ± 0.6; piglets born alive per litter: 10.5 ± 0.6 vs. 10.4 ± 0.4). But the number of stillborn piglets was lower in sows supplemented with L-carnitine than in control sows (0.1 ± 0.2 vs. 0.8 ± 0.2 piglets/litter; $P<0.01$). Piglets and litters of sows supplemented with L-carnitine were 9 and 9%, respectively, heavier at birth than those of control sows (values in control sows vs. L-carnitine supplemented sows: weight of piglets: 1.28 ± 0.07 vs. 1.40 ± 0.07 kg; weights of litters: 13.2 ± 0.6 vs. 14.4 ± 0.6 kg). Differences in weights of piglets and litters were not statistically significant, however. Feed intake of

the sows during lactation and body weight at weaning did not differ between the two groups of sows (values in control sows vs. L-carnitine supplemented sows: feed intake during lactation: 5.2 ± 0.2 vs. 5.3 ± 0.1 kg; body weight at weaning: 179 ± 3 vs. 183 ± 5 kg).

Table II: Nutrient composition and energy content of colostrum and milk of days 10 and 20 of control sows and sows supplemented with L-carnitine[1]

	Control	+ L-carnitine	P
Number of sows	N=13	N=14	
Colostrum[2]			
Protein (g/L)[3]	80 ± 5	108 ± 5*	<0.001
Fat (g/L)[3]	66 ± 8	55 ± 8	0.29
Lactose (g/L)[3]	29 ± 2	28 ± 2	0.65
Gross energy (MJ/kg)[3]	4.98 ± 0.29	5.16 ± 0.28	0.66
IgM (g/L)[4]	6.1 ± 0.3	6.3 ± 0.4	0.65
IgA (g/L)[4]	12 ± 1	10 ± 1	0.12
IgG (g/L)[4]	58 ± 4	58 ± 5	0.96
Milk of day 10			
Protein (g/L)[3]	54 ± 2	55 ± 2	0.51
Fat (g/L)[3]	82 ± 4	92 ± 4	0.08
Lactose (g/L)[3]	48 ± 2	47 ± 1	0.60
Gross energy (MJ/kg)[3]	5.37 ± 0.18	5.69 ± 0.16	0.19
Milk of day 20			
Protein (g/L)[3]	61 ± 1	60 ± 1	0.64
Fat (g/L)[3]	97 ± 4	94 ± 4	0.66
Lactose (g/L)[3]	51 ± 2	51 ± 2	0.99
Gross energy (MJ/kg)[3]	6.08 ± 0.19	5.96 ± 0.19	0.65

[1] Results are LSmeans ± SE. * significantly different from control (P<0.05).
[2] Colostrum was collected 5-8 hours after birth.
[3] Concentrations in whole milk.
[4] Concentrations in whey.

Milk composition

Colostrum had generally higher concentrations of protein and lower concentrations of fat and lactose than milk of days 10 and 20 of lactation. Concentrations of fat and lactose did not differ between control sows and sows supplemented with L-carnitine in colostrum and milk of days 10 and 20 (Table II). The protein concentration in colostrum, however, was higher in sows supplemented with L-carnitine than in control sows (P<0.05) while the protein concentration in milk of days 10 and 20 did not differ between both groups of sows (Table II). The ratio between the concentration of protein and that of fat in the colostrum tended to be higher in sows supplemented with L-carnitine than in control sows (2.27 ± 0.27 vs. 1.61 ± 0.28 g/g, P=0.10). The concentration of the main immunoglobulines – IgG, IgA and IgM – in colostrum did not differ between control sows and sows supplemented with L-carnitine (Table II).

Table III: Suckling behaviour (number of sucklings per day, average duration of one suckling, average duration between two sucklings and total suckling time per day) of piglets of control sows and piglets of sows supplemented with L-carnitine on day 3 of age

	Control	+ L-carnitine	P
Number of sows	N=10	N=10	
Number of sucklings per day (n)	43.0 ± 1.5	44.3 ± 1.5	0.54
Average duration of one suckling (min)	4.80 ± 0.33	5.89 ± 0.33*	0.03
Total suckling time/day (h)	3.44 ± 0.27	4.35 ± 0.27*	0.03
Average time between two sucklings (min)	27.8 ± 0.2	25.1 ± 0.2	0.08

[1] Results are LSmeans ± SE. * significantly different from control (P < 0.05).

Suckling behaviour of the piglets

The number of sucklings per day was not different between piglets of control sows and those of sows supplemented with L-carnitine (Table III). The average duration of one suckling and the total suckling time per day was however significantly higher in piglets of sows supplemented with L-carnitine than in piglets of control sows ($P<0.05$, Table III). The average time between two sucklings tended to be lower in piglets of sows supplemented with L-carnitine than in control sows ($P=0.08$, Table III).

DISCUSSION

Recently, it has been observed that piglets of sows supplemented with L-carnitine are growing faster during the suckling period and have higher weights at weaning than piglets of control sows (Musser et al. 1999, Eder et al. 2001, Ramanau et al. 2002, 2004, 2005). This study was performed to investigate whether L-carnitine supplementation influences the nutrient composition of the milk in sows which could be a potential explanation for an altered growth rate of their piglets observed in recent studies. It is shown that supplemental L-carnitine during gestation and lactation does not influence concentrations of protein, fat and lactose and the energy content of the milk at days 10 and 20 of lactation. This agrees with a recent study in which concentrations of nutrients and energy were similar in milk of control sows and sows supplemented with L-carnitine at day 11 of lactation (Ramanau et al. 2004). In the present study, sows supplemented with L-carnitine had an increased concentration of protein in colostrum. It may be that the increased concentration of protein in colostrum of sows supplemented with L-carnitine enhanced the initial growth of the piglets for a few days after birth. However, because colostrum with a high concentration of protein is secreted only for a few days after parturition the increased concentration of protein was probably not responsible for the increased postnatal growth rates of piglets of supplemented sows observed during the whole suckling period in the recent studies. The reason for the increased concentration of protein in colostrum is unclear. In growing pigs, L-carnitine supplementation stimulated protein synthesis by an increased utilisation of fatty acids and a reduced oxidation of amino acids. These metabolic alterations resulted in an increased protein accretion and a reduced deposition of body fat in pig carcass (Heo et al. 2000, Owen et al. 2001a, b). In colostrum of sows supplemented with L-carnitine there was also a tendency towards an increased ratio between protein and fat. This suggests that L-carnitine could have influenced the metabolism of fat and amino acids in sows similarly as in growing pigs. This suggestion, however, remains to be elucidated.

Immunoglobulines in the milk play an important role for the passive immunisation of the piglet. Their concentrations in milk are highest immediately after birth and are rapidly declining during the first three days of lactation. The pattern of the three main immunoglobulines – IgG, IgM and IgA – determined in the colostrum samples agreed as well as their absolute concentrations agreed well with data reported in literature for immunoglobuline concentrations in colostrum samples 6 h after birth (Blecha 1998). The present study reveals that L-carnitine supplementation does not influence the concentration of immunoglobulines in the milk of sows. It is concluded therefore that L-carnitine in sows does not influence the immunisation of piglets by colostrum.

We have recently observed that piglets of sows supplemented with L-carnitine are able to suckle for a longer time than piglets of control sows which might enable them to suckle more milk from the sow (Birkenfeld et al. 2006b). In this study, we took the opportunity to determine the suckling behaviour of the piglets in the early suckling period. Although the suckling behaviour of the piglets was determined for technical reasons only at one day (day 3) within the suckling period, the data confirm that L-carnitine supplementation of sows improves the suckling behaviour of the piglets. Number of sucklings, average duration of one suckling and total suckling time per day of the piglets observed were similar with those observed on day 3 in our previous study (Birkenfeld et al. 2006b). The suckling frequency of sows shows naturally large individual variations. According to Jensen et al. (1991), the interval between two sucklings in the first week of lactation lies in the range between 30 and 70 minutes. Similarly, Barber et al. (1955) reported an average interval between two sucklings of 51 (range 26 to 96) minutes in piglets on day 6 of life. Accordingly, the average interval between two sucklings observed in our study, being 28 and 25 minutes in piglets of control sows and piglets of L-carnitine treated sows, respectively, appears to be quite low. This might be due to the method used for the study of the suckling behaviour. We defined one suckling act as the time in which at least 60% of the piglets of one litter (5 of 8 piglets) nursed the udder of the sow. If one suckling would have defined as the time in which all piglets were nursing the udder,

average number of sucklings would be smaller and average times per suckling would be shorter while average intervals between two sucklings would be longer.

In conclusion, this study shows that L-carnitine supplementation of sows does not influence concentrations of nutrients and the energy content in mature milk of sows. In colostrum, the protein concentration was increased in sows supplemented with L-carnitine but energy content and concentrations of immunoglobulines were unchanged compared to control sows. It could be confirmed, however, that piglets of sows supplemented with L-carnitine are able to suckle for a longer time than piglets of control sows. These observations indicate that the increased postnatal growth of piglets from sows supplemented with L-carnitine observed in recent studies is caused by an increased milk intake due to an increased suckling time of the piglets while milk composition does not play a major role for this effect.

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Originalarbeit V

Effect of L-carnitine supplementation on pregnancy rate, litter sizes and litter weights in sows

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ABSTRACT
We evaluated three sow experiments to study the effect of L-carnitine on pregnancy rate and litter sizes and litter weights in sows. All three experiments were performed with gilts which received nutritionally adequate diets during pregnancy and lactation. The treated sows received 125 mg L-carnitine/day during pregnancy and 250 mg L-carnitine/day during lactation; control sows did not receive L-carnitine. All three experiments were performed over three consecutive reproductive cycles and were similar in conductance. Total number of pregnancies evaluated was 93 in the control group and 111 in the L-carnitine treated group. Feed intake during pregnancy as well as body weights and backfat thicknesses at the beginning and the end of pregnancy did not differ between both groups of sows. However, sows supplemented with L-carnitine had a higher pregnancy rate (85 vs. 74%, $P<0.05$) and heavier litters (14.4 vs. 13.8 kg/litter, $P<0.05$) than control sows. There was also a tendency towards a higher number of piglets born alive per litter in sows supplemented with L-carnitine than in control sows (11.9 vs. 11.0, $P=0.07$). This study confirms that L-carnitine supplementation has beneficial effects on the reproductive performance of sows. In particular, it is shown for the first time that L-carnitine increases the pregnancy rate in sows.

Keywords: L-carnitine; sow; pregnancy rate; litter size; litter weight

INTRODUCTION
Previous studies have shown that supplementation of sows with L-carnitine increases their reproductive performance. Sows supplemented with L-carnitine had higher piglet and litter weights at birth (Musser et al., 1999; Eder et al., 2001; Ramanau et al., 2002) and piglets of sows supplemented with L-carnitine are growing faster during the suckling period than piglets of control sows (Musser et al., 1999; Ramanau et al., 2004, 2005). Musser et al. (1999) observed increased concentrations of IGF-I and insulin in sows supplemented with L-carnitine and suggested that this could have stimulated intrauterine growth of fetuses. A recent study by us showed that sows supplemented with L-carnitine have heavier placentae than control sows (Doberenz et al., 2006). This finding suggests that L-carnitine improved the intrauterine nutrition of the fetuses by an increased transplacentar transfer of nutrients from the mother to the fetuses. Increased growth rates of piglets during the suckling period might be due to increased milk intake, probably as a result of an increased suckling activity (Ramanau et al., 2004, 2005; Birkenfeld et al., 2006). Besides number and weights of piglets at birth and postnatal growth of the piglets, the number of sows which become pregnant (pregnancy rate) is an important parameter in practical pig production. To our knowledge, the effect of L-carnitine on the pregnancy rate in sows has not yet been investigated. In this study, we determined the effect of L-carnitine on the pregnancy rate in sows. For this purpose, we considered data of three recently conduced sow experiments, conducted over three consecutive reproduction cycles each and determined the pregnancy rate in these sows. Besides the pregnancy rate, we also determined number of piglets and weights of pigs and litters at birth.

MATERIAL AND METHODS
Animals and housing
All animal procedures described followed established guidelines for the care and handling of laboratory animals and were approved by the regional council of Saxony-Anhalt.
For this study, sows of three consecutive experiments were considered. The three experiments were similar in conductance. Each experiment included 40 crossbred gilts (German Landrace x Large White). Average body weights of the sows in the three experiments were 144, 136 and 142 kg, respectively. The sows were acquired from a local breeder and were assigned to two groups of 20 animals each. Their sexual cycle was blocked for 15 days by administration of Altrenogest (Regumate®, Hoechst Roussel Vet. N.V., Frankfurt, Germany). Twenty-four hours after the last dose of Regumate they were injected with 800 IU PMSG followed 80 h later by an injection of 500 IU hCG (Ovogest®5000, Intervet). Twenty-four hours after the hCG injection they were artificially inseminated with sperm of Pietrain boars, followed by a second injection 14 h later. The sows were kept in single crates until day 30 of pregnancy. Between 30 and 35 days after the second insemination, the sows were scanned by ultrasound for pregnancy. Sows who failed to conceive were removed from the experiment. From day 30 to 110 of pregnancy the sows were kept in groups of six to eight in pens measuring 45 m^2 which had fully slatted floors, nipple drinkers and

electronic feeding stations (Type IVOG 2FR VH, HokoFarm, Insentec B.V., Marknesse, The Netherlands). On day 110 of pregnancy they were moved to the farrowing accommodation where they were housed in single farrowing pens. Prior to farrowing rubber mats were put down as lying surface for the piglets. An infrared heater was suspended above each rubber mat to keep the temperature for the newborn piglets at a constant 35°C. The climate in the dry sow accommodation and the farrowing unit was maintained at a temperature of 19 ± 2°C and 60-80% relative humidity by means of an air conditioning system. A light-dark cycle (12-hour light : 12-hour dark) was applied.

Table 1: Composition of the diets used during pregnancy and lactation in Experiments 1, 2, 3

	Experiment 1		Experiment 2		Experiment 3	
	Pregnancy	Lactation	Pregnancy	Lactation	Pregnancy	Lactation
Ingredient (g/kg)						
Dried sugar beet pulp	120	-	300	-	260	-
Barley	77	220	225	263	150	150
Wheat	-	322	-	250	-	344
Wheat bran	300	180	217	80	380	170
Green meal	-	-	-	-	-	-
Wheat meal	-	-	-	80	-	-
Peas	20	50	-	80	-	-
Maize	-	-	-	-	-	80
Triticale	138	-	-	-	25	-
Soybeans	-	-	-	-	-	30
Extracted soy bean meal	-	140	20	106	-	160
Oat bran	-	-	70	-	-	-
Malt sprouts	-	-	69	-	-	-
Rapeseed cake	13	-	-	-	-	-
Extracted sunflower meal	50	-	50	-	110	-
Wheat gluten feed	-	30	28	57	33	-
Vegetable oil	-	24	-	25	2	27
Alfalfa meal	250	-	-	15	-	-
Molasses	20	-	8.7	-	25	-
Calcium carbonate	-	-	4.4	11.3	-	-
Dried yeast	-	-	-	10	-	-
Sodium chloride	-	-	3.5	6	-	-
Monocalcium phosphate	-	-	-	1	-	-
Vitamin and mineral premix including L-lysine and DL-methionine	12	34	4.4	15.7	15	39
Nutrients					-	-
Crude protein (g/kg)	150	178	138	173	138	182
Crude fibre (g/kg)	114	48	124	45	120	48
Crude ash (g/kg)	62	58	74	52	60	46
Crude fat (g/kg)	30	61	27	52	30	59
Lysine (g/kg)	7.0	9.5	6.4	9.9	6.5	10.0
L-carnitine (mg/kg)	16	4	10	3	7	3
Metabolisable energy (MJ ME/kg)[a]	9.5	13.0	9.0	13.0	9.0	13.4

[a] Calculated according to recommendations by Gesellschaft für Ernährungsphysiologie (1987)

After weaning, the trial continued for a second and a third, respectively, reproductive cycle. Twenty-four hours after weaning of their first or second litter, respectively, the sows received 800 IU of pregnant mare serum gonadotropin (PMSG, Intergonan®6000, Intervet, Unterschleißheim, Germany) by intramuscular injection to stimulate oestrus. Seventy-two hours later they were injected with 500 IU human chorionic gonadotropin (hCG, Ovogest®5000, Intervet). Twenty-six hours after that they were artificially inseminated with sperm of Pietrain boars, followed by a second insemination 14 hours later.

Diets, feeding and L-carnitine supplementation

In all three experiments, nutritionally adequate commercial diets for gestating and lactating sows were used. Types of diets used in the three experiments and their nurtrient concentrations are shown in Table 1. Until day 110 of pregnancy, the gestation diet was offered for ad libitum consumption. From day 110 to farrowing each sow was fed 2.5 kg of the gestation diet per day. On the day of farrowing the sows were fed 1.5 kg of the lactation diet, which was then successively increased (3 kg/day on day 1 and day 2 of lactation; 4.5 kg/day on day 3 and day 4 of lactation; ad libitum consumption from day 5 of lactation to weaning). From weaning until the next insemination, the sows were fed 2.5 kg gestation diet per day. Water was provided from nipple drinker systems throughout the whole feeding period.

Supplementation of L-carnitine in the treatment group was started in the gilts 21 days before insemination. Until insemination and throughout the entire pregnancy sows in the treatment group were supplemented with 125 mg L-carnitine per day. During lactation they were given 250 mg of L-carnitine per day. L-carnitine was supplied as tablets containing L-carnitine (62.5 mg/tablet), lactose and dextrose, supplied by Lohmann Animal Health (Cuxhaven, Germany). Each sow was given two tablets once daily in the morning (0900 h) by hand during pregnancy and two tablets twice daily (0900, 1600 h) during lactation. The L-carnitine dosage was based on our recent studies (Eder et al., 2001; Ramanau et al., 2002). Control animals were given placebo tablets without L-carnitine.

Data recording

Sows were weighed (using scales with an accuracy of ± 100 g) on days 1 and 110 of pregnancy and at weaning. The number of piglets born (total, number born alive and number stillborn) was recorded. Individual piglets were weighed at birth (not later than 6 h after birth) with an accuracy of ± 10 g. Backfat thickness of the sows was measured on days 1 and 110 of pregnancy and at weaning by placing the probe of the ultrasound machine (Type SSD500, Aloka, Meerbusch, Germany) vertically 5 cm left of the spinal column at the level of the $13^{th}/14^{th}$ rib. To minimise the measuring error the measurement was repeated 5 cm cranial and 5 cm caudal to the first measuring site. The three readings were combined to form the mean.

Statistical analysis

The statistical analysis of the data was performed with the SAS package (version 9.1.3; SAS Institute, Cary, NC, USA). The traits litter size, litter weight, piglets' body weight, feed intake of the sows during pregnancy and lactation, backfat thickness and body weight of sows were assumed as normal distributed. A mixed linear model (procedure MIXED) with four fixed effects was used. Sows' diet (control, +L-carnitine), trial (1, 2, 3), and the cycle effect (1, 2, 3) and the interaction between these factors were included as fixed effects. Because some sows were used over several cycles, besides the random error effect a random sow effect was included in the model. As the data were unbalanced, we used a method of variance component estimation restricted maximum likelihood (REML) and for degrees of freedom approximation in hypothesis tests the method described by Kenward and Roger (1997). For statistical significant F-values, individual mean values were compared by Tukey-Kramer test to ensure experiment-wise control of statistical error first kind. Values in the text are least square mean ± SEM.

For pregnancy rate a binomial distribution was assumed. Results of the three experiments were evaluated by a generalised linear mixed model (procedure GLIMMIX) which included three fixed effects (experiment, cycle, treatment) and the random sow effect. A logit function was used as link function. The GLIMMIX-procedure provides the linear predictors of the effects under investigation and their (co)variance matrix. The probabilities and their standard errors, given in the results, are calculated by using the inverse function of the logit function. In total, 125 control sows (60 gilts, 43 sows of the 2nd reproductive cycle, 22 sows of the 3rd reproductive cycle) and 133 L-carnitine treated sows (60 gilts, 48 sows of the 2nd reproductive cycle, 26 sows of the 3rd reproductive cycle) were considered for evaluation of the pregnancy rate. 93 control sows (44 gilts, 34 sows of the 2nd reproductive cycle, 15 sows of the 3rd reproductive cycle) and 111 L-carnitine treated sows (51 gilts, 39 sows of the 2nd reproductive cycle, 21 sows of the 3rd reproductive cycle) were considered for evaluation of feed intake, body weights and backfat thickness of sows, number of piglets and piglet and litter weights.

RESULTS

Effect of L-carnitine supplementation on feed intake, body weights and backfat thicknesses of the sows

Feed intake of the sows during pregnancy tended to be lower in sows supplemented with L-carnitine than in control sows (P=0.08, Table 2) while feed intake during the lactation was higher in sows supplemented with L-carnitine than in control sows (P<0.05, Table 2). Body weights and backfat thicknesses on days 1 and 110 of pregnancy and on the day of weaning did not differ between both groups of sows (Table 2). Regarding feed intake, body weights and backfat thicknesses, there were no interactions between treatment and cycle (Table 2).

Table 2: Effect of L-carnitine on feed intake, body weight and backfat thickness during pregnancy and lactation in control sows and sows supplemented with L-carnitine in average of three reproductive cycles

	Treatment		ANOVA, P=			
	Control N=93	L-carnitine N=111	Treatment	Cycle	Experiment	Treatment x cycle
Feed intake, pregnancy (kg)	3.62 ± 0.07	3.45 ± 0.06	0.08	0.20	<0.001	0.15
Feed intake, lactation (kg)	5.26 ± 0.08	5.51 ± 0.07	0.02	<0.001	<0.001	0.90
Body weight, day 1 (kg)	177 ± 2	180 ± 2	0.19	<0.001	0.60	0.11
Body weight, day 110 (kg)	249 ± 2	250 ± 2	0.67	<0.001	<0.001	0.83
Body weight, weaning (kg)	203 ± 3	205 ± 3	0.50	<0.001	<0.001	0.92
Backfat thickness, day 1 (mm)	16.1 ± 1.9	18.1 ± 1.6	0.42	0.80	0.37	0.71
Backfat thickness, day 110 (mm)	22.1 ± 0.5	22.6 ± 0.4	0.46	<0.001	0.50	0.39
Backfat thickness, weaning (mm)	15.9 ± 0.5	16.2 ± 0.4	0.68	<0.001	0.07	064

Results are LSmeans ± SE

*significant differences between control group and treated group (P < 0.05)

Effect of L-carnitine supplementation on pregnancy rate

L-carnitine supplementation had a significant effect (P<0.05) on the pregnancy rate of the sows while effects of experiment and cycle were not significant (Table 3). The interaction between treatment and cycle was also not significant (Table 3). In average of all three experiments and the three reproductive cycles, sows supplemented with L-carnitine had a higher pregnancy rate than control sows (P<0.05, Table 3). In gilts, the effect of L-carnitine supplementation on the pregnancy rate was also significant (Table 4, P<0.05). For sows in the 2^{nd} and 3^{rd} reproductive cycle L-carnitine also increased pregnancy rates slightly, but these effects were not statistically significant (Table 4).

Effect of L-carnitine supplementation on number of piglets born and litter and piglet weights at birth

Sows supplemented with L-carnitine showed a tendency towards a higher number of total born piglets (P=0.13) and piglets born alive (P=0.07) (Table 3). There was a significant interaction between treatment and cycle on number of total born piglets (P=0.05, Table 3). The effect of L-carnitine in this respect was stronger in the second cycle than in the first or the third parity (Table 4). The number of stillborn piglets was not influenced by L-carnitine supplementation of the sows (Table 3). Litter weights were significantly increased by L-carnitine supplementation (P<0.05, Table 3). In average of all cycles, piglet weights were not influenced by L-carnitine supplementation (Table 3).

Table 3: Effects of L-carnitine supplementation on rate of pregnancy, litter sizes and litter and piglet weights in control sows and sows supplemented with L-carnitine in average of three reproductive cycles

	Treatment		ANOVA, P=			
	Control	L-carnitine	Treatment	Cycle	Experiment	Treatment x cycle
	N=125	N=133				
Rate of pregnancy (%)	74.0 ± 4	85.4 ± 3*	0.05	0.182	0.364	0.349
	N=93	N=111				
Piglets born total (n)	11.4 ± 0.4	12.2 ± 0.4	0.13	0.002	0.62	0.05
Piglets born alive (n)	11.0 ± 0.4	11.9 ± 0.3	0.07	0.001	0.30	0.05
Piglets stillborn (n)	0.46 ± 0.11	0.44 ± 0.10	0.22	0.47	0.001	0.72
Litter weights (kg)	13.8 ± 0.5	14.4 ± 0.5*	0.02	<0.0001	0.04	0.26
Piglet weights (kg)	1.42 ± 0.03	1.38 ± 0.03	0.75	<0.0001	0.002	0.04

Results are LSmeans ± SE
*significant differences between control group and treated group (P < 0.05)

However, there was a significant interaction between treatment and cycle indicating that the effects of L-carnitine on piglet weights were different in the three cycles. In the first cycle, L-carnitine supplementation did not influence piglet weights (Table 4). In the second cycle, piglets of L-carnitine supplemented sows were lighter while and in the third cycle they were heavier than piglets of control sows (Table 4).

Table 4: Effects of L-carnitine supplementation on rate of pregnancy, litter sizes and litter and piglet weights in control sows and sows supplemented with L-carnitine in the three cycles

Cycle	Cycle 1		Cycle 2		Cycle 3	
Treatment	Control	L-carnitine	Control	L-carnitine	Control	L-carnitine
	N=60	N=59	N=43	N=48	N=22	N=26
Rate of pregnancy (%)	75.3 ± 6	91.8 ± 4*	81.2 ± 6	83.5 ± 5	63.3 ± 1	77.9 ± 9
	N=44	N=51	N=34	N=39	N=15	N=21
Piglets born total (n)	10.5 ± 0.5	11.1 ± 0.5	10.8 ± 0.5	13.1 ± 0.5*	12.9 ± 0.8	12.5 ± 0.7
Piglets born alive (n)	10.1 ± 0.5	10.7 ± 0.4	10.4 ± 0.5	12.8 ± 0.5	12.6 ± 0.8	12.4 ± 0.7
Piglets stillborn (n)	0.5 ± 0.1	0.4 ± 0.1	0.5 ± 0.1	0.3 ± 0.1	0.4 ± 0.2	0.2 ± 0.2
Litter weights (kg)	13.8 ± 0.5	14.4 ± 0.5	16.4 ± 0.6	18.7 ± 0.6*	17.6 ± 0.9	19.1 ± 0.8
Piglet weights (kg)	1.42 ± 0.04	1.38 ± 0.03	1.62 ± 0.04	1.50 ± 0.04*	1.45 ± 0.06	1.58 ± 0.05*

Results are LS means ± SE
*significant differences between control group and treated group (P<0.05)

DISCUSSION

In this study, the effects of L-carnitine supplementation on pregnancy rate, litter sizes and weights of piglets and litters in sows were determined. For this purpose, we evaluated the results of three sow experiment which were conducted over three reproductive cycles each. Evaluation of these experiments confirms that L-carnitine supplementation of sows increases litter weights. This has been found already in recent experiments with a much larger number of sows (Musser et al., 1999; Eder et al., 2001; Ramanau et al. 2002). As piglet weights did not differ between control sows and sows treated with L-carnitine in average of the three reproductive cycles, increased litter weights were due to the slightly higher number of piglets born in the group of sows supplemented with L-carnitine. The observation that piglets of L-carnitine treated sows were even lighter in the second cycle than those of control sows is surely due to the higher number of piglets born in sows supplemented with L-carnitine.

This study shows for the first time that L-carnitine supplementation increases the pregnancy rate in sows. It is well known that the reproductive function of sows is strongly influenced by backfat thickness. A strong loss of body fat during lactation leading to low body fat stores results not only in an increase of the weaning to estrus interval but also in an increase in subsequent litter size due to effects on embryonal survival (Van der Peet-Schwering, 1998). A minimum percentage of body fat may be linked to onset of puberty and weaning-to-estrus interval in the pig. Numerous genes, i.e. relaxin, interleukins and other cytokines and biologically active substances such as leptin, IGF-I, IGF-II and Agouti protein are produced by porcine adipose tissue, which could have a profound effect on appetite and the reproductive axis Recent studies (Barb et al., 2005). In our study, sows supplemented with L-carnitine consumed more food during the lactation than control sows but they did not differ in body weights or backfat thicknesses at weaning or at insemination. The surplus feed intake in sows supplemented with L-carnitine during lactation probably was used for additional milk intake observed recently (Ramanau et al., 2004, 2005) while their body fat stores at weaning and at insemination did not differ from control sows. Therefore, feed intake, body weights and body fat stores may not play a role for the effects of L-carnitine supplementation on reproductive observed in this study.

The pregnancy rate is depending on the hormonally regulated maturation of follicles in the ovary to fertile oocytes. Follicle stimulating hormone (FSH) and lutenizing hormone (LH), pulsatory released from the pituitary by stimulation with gonadotrope releasing hormone (GnRH), play a key role for the maturation of follicles. FSH stimulates the development of follicles and the synthesis of estrogens. LH stimulates growth of the follicle in the late stage before ovulation (Driancourt et al., 1995; Brüssow et al., 1996). A cyclic increase of the LH concentration in the blood leads to ovulation. LH, moreover, is a luteotropic factor which stimulates the development of the corpus luteum and the release of progesterone. Growth factors such as insulin and insulin-like-growth factor (IGF) I also enhance growth and development of follicles (Hunter et al., 1992; Cox, 1997; Monget and Martin, 1997). Physiologic mechanisms underlying the effects of L-carnitine on reproduction are largely unknown. Literature data, however, suggest that L-carnitine could indirectly affect the hypothalamus-pituitary-gonadal axis in sows via alterations of the concentrations of insulin, IGF-I or leptin in blood. It has been shown that sows supplemented with L-carnitine have higher plasma concentrations of insulin (Musser et al., 1999), IGF-1 (Musser et al., 1999; Doberenz et al., 2006) and leptin (Woodworth et al., 2004) than control sows. Insulin has been shown to be an intermediate between nutrition and reproduction, acting on both hypothalamus-pituitary and ovary level. Exogenous insulin injections in gilts have been found to decrease the number of atretic follicles (Matamoros et al., 1990) and increase the ovulation rate (Cox et al., 1987). In primiparous sows, insulin injections after weaning increased the farrowing rate and the number of live born piglets (Ramirez et al., 1997). Moreover, application of insulin in sows increased the amount of FSH released from pituitary (Cox et al., 1987; Matamoros et al., 1991), plasma LH concentrations (Booth, 1990), and the farrowing rate (Ramirez et al., 1997). Furthermore, a correlation between insulin concentration and LH pulse frequency has been shown in sows (Tokach et al., 1992; Kemp, 1995; Koketsu et al., 1996; Quesnel et al. 1998). IGF-1 stimulates maturation of follicles (Hunter et al., 1992; Cox, 1997; Monget and Martin, 1997). Leptin which is released from white adipose tissue is a hormone with key functions in reproduction. In the pig, nutritional signals such as leptin are detected by the central nervous system and translated by the neuroendocrine system into signals, which regulate appetite, hypothalamic gonadotropin-releasing hormone release and subsequent luteinizing hormone secretion (Barb, 1999). In the anterior pituitary, leptin directly stimulates the release of LH, and to a lesser extent of FSH, independent of central nervous system input (Bajari et al., 2004). Recently, in vitro studies have

shown that leptin has a synergistic role on both oocyte maturation and preimplantation embryo development (Craig et al., 2005). In humans, it has been shown that a lack of leptin or leptin receptor causes a failure to attain pubertal maturity and low serum levels of FSH and LH (Clement et al., 1998; Strobel et al., 1998).

This study also shows a tendency towards an increased number of piglets born alive (+ 0.9 piglets/litter, P=0.07) in sows supplemented with L-carnitine compared to control sows. The number of piglets is determined by the ovulation rate, conception rate, nidation and rate of prenatal survival. As the conception rate is normally very high, mostly being above 95% (Tomes and Nielsen, 1982) and an effect of sperm quality can be ruled out due to the use of identical boar sperm in both groups of sows, it is likely that L-carnitine influenced the ovulation rate or the prenatal survival. Until birth, the number of embryos or fetes is continuously decreasing (Tomes and Nielsen, 1982). However, most losses are occurring before implantation of the embryos into the uterus mucosa. Therefore, the phase until nidation is of particular significance for the litter size. LH is of partical importance for the nidation and embryo survival because it enhances the production of corpus luteum and the production of progesteron. It could be that L-carnitine increases the release of LH due to an increased secretion of insulin (Musser et al., 1999) which in turn could lead to a reduced embryo mortality. This suggestion, however, is speculative and requires experimental examination. It is also unclear why the effect of L-carnitine on the litter size was more pronounced in the second pregnancy than in the first or the third pregnancy. It is known, however, that litter size of 2nd litter is related to sow´s energy metabolism 2 to 4 d before the first postweaning estrus (Armstrong et al. 1986). It could be that L-carnitine supplementation had a particular impact on the energy metabolism in this stage.

In conclusion, the evaluation of three sow experiments shows that L-carnitine supplementation of sows causes an increase in pregnancy rate and litter weights. Moreover, a tendency towards an increased number of piglets born alive was observed in sows supplemented with L-carnitine. These results confirm that L-carnitine supplementation has beneficial effects on the reproductive performance of sows. We suggest that L-carnitine has an impact on the hypothalamus-pituitary-gonadal axis and stimulates the release of FSH or LH from the pituitary. This however remains to be elucidated.

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3. Diskussion

L-Carnitin ist eine, sowohl im menschlichen als auch im tierischen Organismus natürlich vorkommende Substanz, deren Hauptaufgabe darin besteht, den Transport von langkettigen Fettsäuren durch die innere Mitochondrienmembran ins Innere dieser Zellorganelle zu ermöglichen, wo sie für die Energieproduktion durch die ß-Oxidation benötigt werden (FRITZ und YUE 1963, BORUM 1983). Untersuchungen von OWEN et al. (1993) zeigten, dass eine L-Carnitinsupplementierung bei ausgewachsenen Mastschweinen einen geringeren Fettansatz im Körper zur Folge hat. REBOUCHE et al. (1990) und OWEN et al. (1997) stellten fest, dass L-Carnitin wichtige Enzyme des Protein- und Lipidmetabolismus beeinflusst. Demnach nimmt L-Carnitin eine Schlüsselposition im Fett- und Energiestoffwechsel des Organismus ein, was diese Substanz, vor allem für den Einsatz bei landwirtschaftlichen Nutztieren zur Steigerung der Leistung durch erhöhte Energiebereitstellung, besonders interessant macht. Der Schwerpunkt der vorliegenden Arbeit bestand darin, die Wirkung von L-Carnitin speziell bei Sauen und Ferkeln zu untersuchen.

In den letzten Jahren wurden zahlreiche Untersuchungen durchgeführt, welche eine positive Wirkung von L-Carnitin speziell auf die Reproduktions- und Aufzuchtleistung von Sauen belegen (HARMEYER 1993, MUSSER et al. 1999a, b, EDER et al. 2001, RAMANAU et al. 2002, 2004, 2005, DOBERENZ et al. 2006, WAYLAN et al. 2005). In diesen Untersuchungen zeigte sich, dass sich Würfe von mit L-Carnitin supplementierten Sauen durch eine geringere Anzahl an tot geborenen (DOBERENZ et al. 2006) und eine höhere Anzahl an lebend geborenen Ferkeln (HARMEYER 1993, MUSSER et al. 1999a, WAYLAN et al. 2005) mit deutlich höheren Geburtsgewichten (MUSSER et al. 1999a, EDER et al. 2001, RAMANAU et al. 2002, 2004) auszeichnen. Zudem wiesen Ferkel von mit L-Carnitin behandelten Sauen höhere Lebendmassezunahmen während der Säugezeit auf (HARMEYER 1993, RAMANAU et al. 2004, 2005) und zeichneten sich folglich durch höhere Absetzgewichte aus (HARMEYER 1993, EDER et al. 2001, RAMANAU et al. 2002, 2004). In Untersuchungen von REAL (2001) führte eine L-Carnitinsupplementierung von Sauen über zwei Reproduktionszyklen zu einem verkürzten Absetz-Brunst-Intervall sowie zu einem tendenziell früheren Brunsteintritt im ersten Zyklus und einer tendenziell höheren Abferkelrate im zweiten Zyklus. Die Ursachen dieser, durch L-Carnitinsupplementierung hervorgerufenen, verbesserten Reproduktions- und Aufzuchtleistung von Sauen sowie des gesteigerten postnatalen Wachstums der Ferkel sind jedoch bislang nicht vollends geklärt und sollten in der vorliegenden Arbeit anhand von 5 eigenen Studien weiter beleuchtet werden.

3.1. L-Carnitin und Fruchtbarkeit

Im Sektor Schweineproduktion ist derzeit die Fruchtbarkeitsleistung von Sauen im Vergleich zur Mast- und Schlachtleistung von Mastschweinen der wirtschaftlich bedeutendste Merkmalskomplex. Folglich steht die Fortpflanzungsleistung in ihrer Komplexität, mit dem Ziel einer Steigerung der Ausschöpfung des Reproduktionspotentials, im Mittelpunkt des Interesses von Wissenschaft und

Praxis. Aus diesem Grund wurde eine Studie (2.5.) durchgeführt, in welcher der Effekt einer L-Carnitinsupplementierung von Sauen auf die Trächtigkeitsrate, die Wurfgröße und die Gewichte der Ferkel und Würfe zur Geburt, anhand von 3 Versuchen mit jeweils 3 Durchgängen, untersucht wurde. In dieser Untersuchung zeigte sich, dass eine L-Carnitinsupplementierung über mehrere Reproduktionszyklen bei zyklussynchronisierten Sauen zu einer gesteigerten Trächtigkeitsrate führt. Speziell mit L-Carnitin supplementierte Jungsauen wiesen eine deutlich höhere Trächtigkeitsrate auf als unbehandelte Sauen. Als Trächtigkeits- bzw. Konzeptionsrate wird der Anteil Sauen bezeichnet, welche nach Belegung trächtig werden. Sie wird im Wesentlichen durch die hormonell gesteuerte Entwicklung und Reifung der Follikel in den Ovarien zu befruchtungsfähigen Eizellen während der Brunst bestimmt. Eine besondere Rolle im Fortpflanzungsgeschehen bzw. hinsichtlich der Steuerung der Brunst und der Ovulation spielen das Hypothalamus-Hypophysen-System sowie die Ovarien. Die Ovarien bilden Steroide und der Hypothalamus gilt als übergeordnetes Steuersystem, welches durch pulsatorische Freisetzung von Gonadotropin Realising Hormon (GnRH) die Hypophyse zur Produktion von Follikelstimulierendem Hormon (FSH) und Luteinisierendem Hormon (LH) stimuliert. Während FSH die Entwicklung des Keimepithels und das Follikelwachstum bis 4 mm stimuliert, wirkt LH fördernd auf die weitere Entwicklung und Ausreifung der Follikel (DE RENSIS et al. 1991, DRIANCOURT et al. 1995, BRÜSSOW et al. 1996). Der heranwachsende Follikel bildet zusätzlich Follikelhormone, die im Wesentlichen aus Östradiol bestehen, wodurch über den Hypothalamus die Produktion von FSH gehemmt und die Hypophyse zu einer verstärkten Ausschüttung von LH angeregt wird. Als Folge des zyklischen LH-Anstieges wird die Ovulation ausgelöst (GRANT et al. 1989). Zudem ist LH ein luteotroper Faktor, der die Entwicklung des Corpus luteum und die Freisetzung von, für die Aufrechterhaltung der Trächtigkeit notwendigem, Progesteron stimuliert. Auch Wachstumsfaktoren wie Insulin und insulin-like growth factor-1 (IGF-1) fördern das Wachstum und die Entwicklung der Follikel zu ovulationsfähigen und befruchtungsfähigen Eizellen (HUNTER et al. 1992, COX 1997, MONET und MARTIN 1997). Die physiologischen Mechanismen wie L-Carnitin auf endokrinologischer Ebene die Reproduktions- und Fruchtbarkeitsleistung von Sauen beeinflusst sind nicht vollends geklärt. Literaturdaten lassen jedoch vermuten, dass L-Carnitin indirekt die Hypothalamus-Hypophysen-Gonaden-Achse beeinflusst, was zu Änderungen der Konzentrationen von Hormonen wie Insulin, IGF-1 und Leptin im Sauenblut führt. So zeigten verschiedene Studien, dass mit L-Carnitin supplementierte Sauen höhere Konzentrationen an Insulin (MUSSER et al. 1999a), IGF-1 (MUSSER et al. 1999a, DOBERENZ et al. 2006) und Leptin (WOODWORTH et al. 2004) im Plasma aufweisen als Kontrollsauen.

Das Insulin spielt eine entscheidende Rolle im Reproduktionsgeschehen der Sau, indem es die Freisetzung von Sexualhormonen stimuliert und somit eine Schlüsselposition zwischen Ernährung und reproduktiver Fitness von Sauen einnimmt. Beispielsweise konnte gezeigt werden, dass exogen zugeführtes Insulin zu einer Reduzierung der Follikel Atresie führt (MATAMOROS et al. 1991) und die Ovulationsrate positiv beeinflusst (COX et al. 1987). Weiterhin führte eine Insulinapplikation bei Sauen zu einer gesteigerten FSH-Sekretion der Hypophyse (COX et al. 1987, MATAMOROS et al. 1991), zu erhöhten Konzentrationen an LH im Sauenplasma (BOOTH 1990,

TOKACH 1992b, RAMIREZ et al. 1994, 1997) sowie zu einer gesteigerten Abferkelrate (RAMIREZ et al. 1997). Zudem stellten TOKACH et al. (1992b), KOKETSU et al. (1996) sowie QUESNEL et al. (1998) fest, dass eine hohe Konzentration an Insulin im Plasma von Sauen die Frequenz der LH Freisetzung steigert. Sowohl Insulin als auch IGF-1 im Sauenblut beeinflussen das Wachstum und die Entwicklung der Follikel positiv (HUNTER et al. 1992, COX 1997, MONET und MARTIN 1997). Das IGF-1 spielt scheinbar, durch Interaktion mit Östradiol und FSH, eine entscheidende Rolle bei der Entscheidung welche Follikel bis zur befruchtungsfähigen Eizelle heranreifen und welche der Atresie unterliegen bzw. zurückgebildet werden (HUNTER et al. 1992). Auch konnte in bisherigen Studien eine positive Beziehung zwischen den Plasma IGF-1 Konzentrationen und der LH Sekretion festgestellt werden (PETTIGREW and TOKACH 1993, WHITLEY et al. 1995), welches sowohl die weitere Entwicklung und Ausreifung der Follikel fördert (DE RENSIS et al. 1991, DRIANCOURT et al. 1995, BRÜSSOW et al. 1996) als auch die Ovulation auslöst (GRANT et al. 1989). Ebenfalls eine zentrale Rolle im Fruchtbarkeits- und Reproduktionsgeschehen von Sauen nimmt das Hormon Leptin ein (BARB et al. 1999, CUNNINGHAM et al. 1999, WILLIAMS et al. 2002). In den Adipozyten (Fettgewebszellen) findet die Bildung des Hormons Leptin statt, welches zum einen, durch seine Wirkung auf die Bauchspeicheldrüse und die Sekretion von Insulin, die Nahungsaufnahme und den Kohlenhydratstoffwechsel und zum anderen die Fruchtbarkeits- und Reproduktionsleistung beeinflusst (SCHNURRBUSCH und HÜHN 1994, HOUSEKNECHT et al. 1998, WOODWORTH et al. 2004). Letzteres wird durch einen direkten Einfluss von Leptin auf die Hypophysen-Hypothalamus-Gonaden-Achse bewirkt (CAPRIO et al. 2001, BAJARI et al. 2004). Dass Leptin eine Schlüsselrolle im Fortpflanzungsgeschehen einnimmt, bestätigen weitere Untersuchungen, in denen Leptin in der Plazenta (MASUZAKI et al. 1997) sowie Leptin Rezeptoren in den Ovarien (KARLSSON et al. 1997, RUIZ-CORTES et al. 2000) und Hoden (BANKS et al. 1999) lokalisiert wurden. Hohe Konzentrationen an Leptin im Blut wirken sich positiv auf die Ausschüttung des Gonadotropin-Realising Hormons (GnRH) im Hypothalamus aus, wodurch die Freisetzung von FSH und LH aus der Hypophyse stimuliert wird (YU et al. 1997, BAJARI et al. 2004, BARB et al. 2005). Hierdurch wird wiederum die Entwicklung und Reifung von Follikeln und Eizellen in den Ovarien gefördert.

Die Kenntnisse zur Wirkung von L-Carnitin auf endokrinologischer Ebene und zum Einfluss auf das Fruchtbarkeitsgeschehen bei Sauen sind bislang unzureichend. Jedoch beeinflusst L-Carnitin scheinbar das endokrine System von Sauen und somit die Freisetzung von, für die Trächtigkeit und Reproduktion relevanten Hormonen. Demzufolge ist zu vermuten, dass L-Carnitin durch Steigerung der Konzentrationen an Insulin, IGF-1 und Leptin im Blut von Sauen die Sekretion von FSH und LH stimuliert, welche bei der Entwicklung der Follikel zu befruchtungsfähigen Eizellen und der Steuerung der Ovulation involviert sind, und somit indirekt die Fruchtbarkeitsleistung der Sau beeinflusst.

3.2. L-Carnitin und Wurfgröße

Neben der Trächtigkeitsrate bestimmt weiterhin die Wurfgröße bzw. die Anzahl an lebend geborenen Ferkeln maßgeblich die Reproduktionsleistung der Sau und besitzt große ökonomische

Relevanz. In bisherigen Studien führte eine L-Carnitinsupplementierung, hinsichtlich der Anzahl an lebend geborenen Ferkeln, jedoch zu unterschiedlichen Ergebnissen. Während in einigen Untersuchungen, in Bezug auf die Anzahl an lebend geborenen Ferkeln, kein Unterschied zwischen mit L-Carnitin behandelten und unbehandelten Sauen festgestellt werden konnte, (MUSSER et al. 1997, EDER et al. 2001, RAMANAU et al. 2002, 2005, DOBERENZ et al. 2006), führte eine L-Carnitinsupplementierung von Sauen während der Trächtigkeit in anderen Studien zu einer deutlich gesteigerten Anzahl an lebend geborenen Ferkeln (HARMEYER, 1993, MUSSER et al. 1999a, b, WAYLAN et al. 2005). Auch in eigenen Studien konnte keine einheitliche Wirkung von L-Carnitin auf die Wurfgröße zur Geburt festgestellt werden. Während sich die Anzahl an insgesamt und lebend geborenen Ferkeln in einigen Untersuchungen nicht unterschied (2.2., 2.3.) wiesen in einer weiteren Studie (2.5.), mit deutlich höherem Stichprobenumfang, mit L-Carnitin supplementierte Sauen eine tendenziell erhöhte Anzahl an lebend geborenen Ferkeln sowie eine deutlich höhere Anzahl an insgesamt geborenen Ferkeln im zweiten Reproduktionszyklus auf.

Hinsichtlich der Anzahl an geborenen Ferkeln ist das Ernährungsniveau in der frühen Trächtigkeit nachweislich von besonderer Bedeutung (SOEDE et al. 1999). Eine mangelnde Energieversorgung der Sau während der Gravidität wirkt sich somit negativ auf die Anzahl an geborenen Ferkeln aus (GÜTTE und HEISE 1967, ELSLEY et al. 1969, VERMEDAHL et al. 1969). Besonders bei Jungsauen ist die Reproduktionsleistung suboptimal, da der Wachstumsprozess noch nicht abgeschlossen ist und ein großer Teil der zugeführten Energie für den Körperzuwachs benötigt wird. Zudem wirkt ein nicht vollends entwickelter Gastrointestinaltrakt limitierend auf die Futteraufnahme und somit die zugeführte Menge an Energie und Nährstoffen. Auch die Entwicklung bzw. das Wachstum der Fortpflanzungsorgane, wie Ovarien und Uterus, ist noch nicht vollständig abgeschlossen, was zu kleineren Würfen führt. Demnach könnte die verbesserte Wurfgröße, speziell im zweiten Zyklus der Sauen (2.5.), möglicherweise auf eine verbesserte Energieversorgung der mit L-Carnitin versorgten Sauen während der ersten Laktation zurückzuführen sein. Da L-Carnitin für die Energiebereitstellung im Organismus unerlässlich ist, kann somit vermutet werden, dass eine gesteigerte Wurfgröße Folge einer, durch L-Carnitinsupplementierung hervorgerufenen, erhöhten Energieausnutzung ist. Dies ist lediglich eine Vermutung und in der Literatur wenig belegt.

Zudem wird die Wurfgröße bzw. die Anzahl an insgesamt und lebend geborenen Ferkeln maßgeblich durch die Ovulationsrate, die Befruchtungsrate und die embryonale Überlebensrate bestimmt. Da die Befruchtungsrate normalerweise sehr hoch (>95%) ist (TOMES und NIELSEN 1982) und der Einfluss der Spermaqualität, durch den Einsatz des gleichen Eberspermas in beiden Behandlungsgruppen, auszuschließen ist, kann diese für die Beurteilung des Konzeptionserfolges vernachlässigt werden. Während die Ovulationsrate von der Anzahl der vorhandenen präovulatorischen Follikel abhängt wird die embryonale Überlebensrate von der Qualität der Follikel bestimmt (YANG et al. 2000, FERGUSON et al. 2003). Sowohl die Ovulationsrate als auch die embryonale Überlebensrate können durch die Fütterung beeinflusst werden. So übt beispielsweise ein erhöhtes Energieangebot vor der Besamung einen positiven Effekt auf die Ovulationsrate aus (BROOKS und COLE 1974, REINISCH und SCHNURRBUSCH 1978,

HUGHES et al. 1989). Auch Insulinapplikationen bei Sauen haben eine erhöhte Ovulationsrate zur Folge (COX et al. 1987, MATAMOROS et al. 1990) und führen zu einer Erhöhung der Anzahl an lebend geborenen Ferkeln zur Geburt (RAMIREZ et al. 1997). Erhöhte Insulinspiegel im Blut von Sauen können beispielsweise durch exogene Zufuhr (COX et al. 1987) oder durch erhöhte Energiezufuhr (QUESNEL et al. 1998) hervorgerufen werden, können jedoch auch die Folge einer L-Carnitinsupplementierung sein (MUSSER et al. 1999a). Möglicherweise kann eine Interaktion zwischen einer L-Carnitinzufuhr und einer erhöhten Ovulationsrate, hervorgerufen durch erhöhte Konzentrationen an Insulin im Sauenblut, vermutet werden, welche die Wurfgröße zur Geburt positiv beeinflusst.

Bis zur Geburt reduziert sich die Anzahl Embryos bzw. Föten ständig durch Verluste (TOMES und NIELSEN 1982). Lediglich 30% der befruchtungsfähigen Eizellen vollziehen etwa die Entwicklung von der Ovulation bis zur Geburt des Ferkels (FERGUSON et al. 2003). Nach der Ovulation und erfolgreicher Befruchtung erfolgt die Nidation bzw. die Implantation der befruchteten Eizellen im Uterus. Der Großteil der pränatalen Verluste ereignet sich in der frühen Trächtigkeit, d.h. bis zur Implantation in den Uterus (FERGUSON et al. 2003). Insofern ist diese Phase bis zur Nidation für die Erhaltung der Trächtigkeit und der Wurfgröße entscheidend.

Die embryonale Überlebensrate ist ebenfalls positiv mit dem Ernährungsniveau der Sau korreliert. So wirkt sich ein reduziertes Fütterungsniveau bzw. eine ungenügende Energiezufuhr sowohl bei Jungsauen (ZAK et al. 1997) als auch bei laktierenden Sauen (ALMEIDA et al. 2000) negativ auf die embryonale Überlebensrate aus. Die frühembryonale Überlebensrate (vor der Implantation) ist vor allem von den Embryos und weniger vom Muttertier abhängig (BAZER et al. 1969a, b, BENNETT und LEYMASTER 1989, BLASKO et al. 1992). Möglicherweise könnte eine L-Carnitinsupplementierung von Sauen die Nährstoffversorgung der Follikel bereits im Ovar verbessern und zu einer gesteigerten Ovulationsrate führen, welche sich, bei gleichem Befruchtungserfolg und gesteigerter frühembryonaler Überlebensrate, als Folge einer höheren Vitalität der Embryonen, in einer gesteigerten Wurfgröße bzw. einer höheren Anzahl insgesamt und lebend geborener Ferkel äußern würde.

Während der Trächtigkeit ist besonders das LH von Bedeutung, da es infolge seiner luteotropen Wirkung für die Aufrechterhaltung der Funktion der Trächtigkeitsgelbkörper und deren Progesteronproduktion verantwortlich ist. Ist die Progesteronkonzentration in der frühen Trächtigkeit infolge eines LH-Mangels vermindert, erhöht sich die Rate der embryonalen Mortalität (ASHWORTH et al. 1989, PHARAZYN et al. 1991, JINDAL et al. 1996), was sich wiederum in Form von niedrigen Wurfgrößen äußert. Zahlreiche Studien bestätigen, dass eine höhere Energieversorgung der Sau sowie höhere Konzentrationen an Insulin die LH Sekretion stimulieren und zu höheren Konzentrationen an LH im Blut führen (COX et al. 1987, TOKACH et al. 1992b, KOKETSU et al. 1996, QUESNEL et al. 1998). Da in Untersuchungen von MUSSER et al. (1999a) eine L-Carnitinsupplementierung von Sauen mit erhöhten Insulingehalten im Blut korreliert war, ist zu vermuten, dass L-Carnitin ebenfalls einen positiven Effekt auf die embryonale Überlebensrate ausübt.

Nach der Implantation wird die Überlebensrate der Embryonen zudem entscheidend von der Uteruskapazität des Muttertieres bestimmt (BENNETT und LEYMASTER 1989). Stehen mehr Embryonen zur Verfügung als die Uteruskapazität erlaubt, wird die Wurfgröße von der Kapazität des Uterus limitiert (DZIUK 1968). Es ist nicht auszuschließen, dass L-Carnitin, infolge einer gesteigerten Nährstoffversorgung und Energiebereitstellung, die Entwicklung des Uterus verbessert wodurch die Voraussetzungen zur Implantation der befruchteten Eizellen optimiert werden und somit die Uteruskapazität positiv beeinflusst werden könnte.

3.3. L-Carnitin und Wurfgewicht

Weiterhin wiesen Sauen, die während der Trächtigkeit L-Carnitin erhielten, im Vergleich zur Kontrollgruppe deutlich schwerere Würfe zur Geburt auf (2.5.). Dieser positive Einfluss von L-Carnitin auf die Wurfgewichte von Sauen konnte bereits in zahlreichen anderen Untersuchungen gezeigt werden (MUSSER et al. 1999a, EDER et al. 2001, RAMANAU et al. 2002, 2004). Auch führte eine Supplementierung der Muttersauen während der Trächtigkeit mit L-Carnitin in einigen Untersuchungen zu deutlich höheren Ferkelgewichten zur Geburt (MUSSER et al. 1999a, EDER et al. 2001, RAMANAU et al. 2002,2004, WAYLAN et al. 2005). Ein ähnlicher Trend zeigte sich ebenfalls in einer Untersuchung von DOBERENZ et al. (2006) und einer eigenen Studie (2.2.), in denen eine L-Carnitinsupplementierung der Sauen während der Trächtigkeit zu einer erhöhten Lebendmasse der Ferkel und Würfe zur Geburt führte. Diese Gewichtsunterschiede waren in diesen Untersuchungen, mit deutlich geringerem Stichprobenumfang, jedoch nicht signifikant.

3.4. L-Carnitin und pränatales Ferkelwachstum

Die höheren Geburtsgewichte der Ferkel und Würfe, infolge einer L-Carnitinsupplementierung von Sauen, lassen auf einen positiven Einfluss von L-Carnitin auf das pränatale Wachstum der Ferkel schließen. Die, dem verbesserten Ferkelwachstum, zugrunde liegenden biochemischen Mechanismen sind bislang unklar. Jedoch ist zu vermuten, dass L-Carnitin einen Einfluss auf das endokrine System der Sauen ausübt und die Freisetzung von, für die intrauterine Entwicklung der Ferkel relevanten Hormonen beeinflusst. Tatsächlich konnte in anderen Untersuchungen festgestellt werden, dass mit L-Carnitin supplementierte Sauen während der Trächtigkeit deutlich höhere Konzentrationen an IGF-1 (MUSSER et al. 1999a, DOBERENZ et al. 2006) und IGF-2 (DOBERENZ et al. 2006) im Plasma aufweisen als unbehandelte Sauen. IGF-1 und IGF-2 sind sowohl für die Entwicklung der Plazenta als auch für die transplazentare Versorgung des Fötus mit Nährstoffen von besonderer Bedeutung und beeinflussen somit maßgeblich die intrauterine Entwicklung der Ferkel (KELLEY et al. 1995, STERLE et al. 1995, GLUCKMAN et al. 1997). Zudem wiesen DOBERENZ et al. (2006) nach, dass Sauen, die während der Trächtigkeit L-Carnitin erhielten, schwere Chorions zur Geburt aufweisen als Kontrollsauen. Das Chorion bildet den fötalen Teil der Plazenta beim Schwein. Über eine größere Plazenta mit einer vergrößerten Oberfläche ist vermutlich ein erhöhter Transfer von Nährstoffen vom maternalen Blut zum Fötus zu realisieren, welcher eine verbesserte intrauterine Entwicklung der Ferkel zur Folge hat. Weiterhin stellten DOBERENZ et al. (2006) fest, dass eine L-Carnitinsupplementierung von Sauen während

der Trächtigkeit zu deutlich höheren Proteinkonzentrationen des GLUT-1 (Glukosetransporter-1) in den Chorions führt, welcher eine Schlüsselposition beim Transport von Glukose vom maternalen zum fötalen Blut einnimmt. Da die Versorgung des Fötus mit Glukose grundlegend für das fötale Wachstum ist, schlussfolgerten diese Autoren, dass eine höhere Konzentration an GLUT-1 im Chorion ursächlich für eine verbesserte transplazentare Versorgung des Fötus mit Glukose ist und dies die Erklärung für die höheren Lebendmassen der Ferkel zur Geburt liefert.
In eigenen Untersuchungen (2.2., 2.3.) konnte zudem festgestellt werden, dass eine L-Carnitinsupplementierung von Sauen während der Trächtigkeit zu deutlich gesteigerten L-Carnitingehalten im Plasma und Körper der Ferkel zur Geburt führt, was auf eine verbesserte intrauterine Versorgung der Föten mit L-Carnitin, aufgrund eines erhöhten Transfers dieser Substanz vom maternalen zum fötalen Blut, hindeutet. Die, durch L-Carnitinsupplementierung von Sauen hervorgerufenen, erhöhten Gehalte an L-Carnitin im Körper und Plasma der Ferkel, verbunden mit einer verbesserten intrauterinen Nährstoffversorgung der Föten und einer Stimulierung körpereigener Wachstumshormone wie IGF-1 und IGF-2 während der pränatalen Entwicklungsphase sind bislang als ursächlich für das verbesserte pränatale Wachstum der Ferkel anzusehen.

3.5. L-Carnitin und postnatales Ferkelwachstum

Nach FOXCROFT and TOWN (2004) wird zudem das postnatale Wachstum von Ferkeln bereits während der fötalen Entwicklung im Uterus maßgeblich geprägt. Demnach weisen, durch L-Carnitinsupplementierung von Sauen, intrauterin besser versorgte Ferkel möglicherweise auch nach der Geburt ein verbessertes Wachstum auf. Tatsächlich zeigten bisherige Untersuchungen, dass Ferkel von mit L-Carnitin supplementierten Sauen höhere Lebendmassezunahmen während der Säugezeit aufweisen und sich somit am Ende der Säugezeit durch höhere Lebendmassen auszeichnen als Ferkel von Kontrollsauen (MUSSER et al. 1999a, EDER et al. 2001, RAMANAU et al. 2002, 2004, 2005). Auch in einer eigenen Studie (2.3.) zeichneten sich Ferkel von mit L-Carnitin supplementierten Sauen durch ein gesteigertes Wachstum während der Säugeperiode aus.
Im Fötus ist die ß-Oxidationsrate sehr gering (NOVAK et al. 19981) und die Energiegewinnung erfolgt hauptsächlich durch die Verstoffwechselung von Kohlenhydraten. Da die vorhandenen Glykogenreserven im Ferkelkörper schnell aufgebraucht sind, gewinnt nach der Geburt die ß-Oxidation zur Energieproduktion zunehmend an Bedeutung (WARSHAW und CURRY 1980, GIRARD 1990). Für eine effiziente Verwertung von Fettsäuren zur Energieproduktion über die ß-Oxidation sind jedoch ausreichende Konzentrationen an L-Carnitin im Gewebe erforderlich. In eigenen Untersuchungen (2.2., 2.3.) konnte festgestellt werden, dass eine L-Carnitinsupplementierung von Sauen während der Trächtigkeit zu deutlich gesteigerten L-Carnitingehalten im Plasma und Körper der Ferkel zur Geburt führt. Da die Fähigkeit zur körpereigenen Synthese von L-Carnitin bei Neugeborenen nur sehr schwach ausgebildet ist und sich erst allmählich im Verlauf der ersten Lebenswochen entwickelt (BORUM 1983), sind diese zudem auf eine Zufuhr von L-Carnitin über die Milch angewiesen. Wie in eigenen Untersuchungen (2.2., 2.3.) festgestellt werden konnte, berichten auch RAMANAU et al. (2004, 2005) über erhöhte

L-Carnitingehalte in der Milch von Sauen, die während der Trächtigkeit und Laktation L-Carnitingaben erhielten. Möglicherweise sind Ferkel von mit L-Carnitin behandelten Sauen, durch einen erhöhten L-Carnitinstatus bereits zur Geburt sowie durch eine verbesserte L-Carnitinversorgung während der Laktation über die Sauenmilch, in der Lage frühzeitiger und effizienter die Energieproduktion via ß-Oxidation zu aktivieren. Dies wäre eine mögliche Erklärung für die in bisherigen Studien festgestellten gesteigerten Lebensmassezunahmen der Ferkel von mit L-Carnitin supplementierten Sauen während der Säugezeit (HARMEYER 1993, MUSSER et al. 1999a, EDER et al. 2001, RAMANAU et al. 2002, 2004, 2005).

Weiterhin zeigten MUSSER et al. (1999c), dass Ferkel von mit L-Carnitin supplementierten Sauen zur Geburt eine größere Muskelfläche und eine höhere Anzahl an Muskelfasern des *Musculus semitendinosus* aufweisen als Ferkel von Kontrollsauen und führten das verbesserte postnatale Wachstum auf eine günstigere Körperzusammensetzung der Ferkel zurück. Bei Absetzferkeln und Mastschweinen hatte eine L-Carnitinsupplementierung des Futters tatsächlich eine gesteigerte energetische Nutzung von Fettsäuren zur Folge, welche zu verminderten Körperfettgehalten und gleichzeitig erhöhten Gehalten an Körperprotein führte (OWEN et al. 1996, HEO et al. 2000, OWEN et al. 2001). Eigene Untersuchungen (2.2.) zeigten jedoch, dass Ferkel von mit L-Carnitin behandelten Sauen, im Vergleich zu Ferkeln von Kontrollsauen, hinsichtlich ihrer Körperzusammensetzung und des Lipidmetabolismus am Tag der Geburt sowie am 10. und 20. Lebenstag keinerlei Unterschiede aufweisen. Sie wiesen jedoch bereits zur Geburt, aufgrund eines erhöhten Transfers von L-Carnitin aus dem maternalen Blut zum Fötus, als auch am 10. und 20. Lebenstag durch eine verbesserte L-Carnitinversorgung über die Milch, einen höheren L-Carnitinstatus im Blut sowie im Körper auf. Gesteigerte Konzentrationen an L-Carnitin im Gewebe und Plasma der Ferkel führen zu einer erhöhten CPT-1 Aktivität sowie einer gesteigerten ß-Oxidationsrate von langkettigen Fettsäuren in der Leber (PENN et al. 1997, HEO et al. 2000b) und könnten demzufolge ein verbessertes Wachstum vermuten lassen.

Das postnatale Ferkelwachstum wird zudem maßgeblich von der Milchleistung der Sau (NOBLET and ETIENNE 1987, KING et al. 1993) sowie der Energie- und Nährstoffaufnahme der Ferkel über die Sauenmilch beeinflusst (PLUSKE und DONG 1998). Da Sauenmilch in den ersten Lebenstagen die einzige Nahrungsquelle für die Ferkel darstellt, ist zu vermuten, dass schneller wachsende Ferkel über die Milch besser bzw. mit mehr Nährstoffen versorgt werden. Eine erhöhte Nährstoffaufnahme der Ferkel könnte demnach auch Folge einer gesteigerten Milchleistung der Sau sein.

Die Milchleistung von Sauen ist von einer Vielzahl von Faktoren abhängig. Beispielsweise spielt das Alter sowie die Energie- und Nährstoffversorgung der Sau eine entscheidende Rolle (TOKACH et al. 1992a, BOYD et al. 1995). Es ist bekannt, dass eine stark positive Korrelation zwischen dem Fütterungsniveau und der von der Sau produzierten Milchmenge besteht (NOBLET et al. 1998). Bereits eine geringe Restriktion der Energieaufnahme kann eine starke Reduktion der Milchleistung der Sau während der Laktation zur Folge haben (VAN DEN BRAND et al. 2000). Studien von RAMANAU et al. (2005) zeigten jedoch, dass mit L-Carnitin supplementierte Sauen sogar bei ungenügender Nährstoffzufuhr im Zustand einer negativen Energiebalance, durch eine

erhöhte Mobilisation von Körperfettreserven, in der Lage sind die Milchleistung während der Laktation auf hohem Niveau aufrecht zu halten (RAMANAU et al. 2005). Auch in weiteren Untersuchungen von RAMANAU et al. (2004, 2005) führte eine L-Carnitinsupplementation während der Trächtigkeit und Laktation zu einer gesteigerten Milchproduktion der Sauen am 11. und 18. Laktationstag.

Als Indikator für die Leistungsfähigkeit der Sau zur Milchproduktion kann laut NIELSEN und SORENSEN (1998) die Größe der Milchdrüse genutzt werden. Tatsächlich zeigte eine Studie von FELGNER (2004), dass sowohl das Gewicht, die DNA-Konzentration und die Aktivität der lipogenen Enzyme als auch die Querschnittsfläche der Milchdrüse durch orale L-Carnitingaben an Sauen erhöht wird. Somit kann davon ausgegangen werden, dass die in bisherigen Untersuchungen beobachtete stärkere Gewichtszunahme der Ferkel während der Laktation im Wesentlichen durch eine höhere Milchproduktion der mit L-Carnitin supplementierten Sauen hervorgerufen wird. Nun stellt sich die Frage nach den Ursachen der gesteigerten Milchleistung.

Nach SPINKA et al. (1997) und ETIENNE et al. (1998) ist das Säugeverhalten der Ferkel ein wichtiger Faktor, der die Milchabgabe und somit das Wachstum der Ferkel beeinflusst. Ferkel, die öfter und intensiver Säugen, mit kürzeren Intervallen zwischen den Saugakten, sind in der Lage mehr Milch aufzunehmen und gleichzeitig die Milchsynthese anzuregen (AULDIST et al. 1998, SPINKA et al. 1997). Dies führt zu einem erhöhten Gewicht der Milchdrüse und zu einer gesteigerten Milchproduktion während der Laktation (AULDIST et al. 2000). In eigenen Untersuchungen (2.3., 2.4.) konnte nachgewiesen werden, dass Ferkel von Sauen, die während der Trächtigkeit und Laktation einer L-Carnitinsupplementierung unterlagen, in der frühen Laktationsphase deutlich längere Säugezeiten und somit kürzere Zeiten zwischen den Saugakten aufweisen. Dies erklärt die, bei mit L-Carnitin supplementierten Sauen festgestellten, erhöhten Milchdrüsengewichte (FELGNER, 2004) und zeigt, dass die verbesserten Lebendmassezunahmen der Ferkel während der Säugeperiode auf ein verbessertes Säugeverhalten verbunden mit einer gesteigerten Milchaufnahme zurückzuführen sind. Ferkel, die längere Säugezeiten aufweisen, massieren das Gesäuge der Sau nach der Milchejektion auch länger, wodurch wiederum die Milchproduktion der Sau positiv beeinflusst wird (ALGERS and JENSEN 1991). Wodurch sind jedoch die verlängerten Säugezeiten der Ferkel von Sauen, die während der Trächtigkeit und Laktation L-Carnitin erhielten, zu erklären?

In einer weiteren Studie (2.3.) konnte die positive Wirkung von L-Carnitin auf das Säugeaktivitätsverhalten und die Lebendmassezunahmen der Ferkel vorrangig auf pränatale Effekte, also durch L-Carnitinsupplementierungen der Sauen während der Trächtigkeit, zurückgeführt werden. Das heißt Ferkel, welche von Sauen geboren wurden, die während der Trächtigkeit L-Carnitingaben erhielten, wiesen deutlich längere Säugezeiten und höhere Lebendmassezunahmen während den ersten 14 Lebenstagen auf, auch wenn sie während der Laktation von Kontrollsauen gesäugt wurden. Diese Beobachtung demonstriert, dass die Effekte einer L-Carnitinsupplementierung von Sauen während der Trächtigkeit für das gesteigerte postnatale Wachstum der Ferkel verantwortlich sind und eine Supplementierung von laktierenden Sauen mit L-Carnitin das Wachstum der Ferkel nicht beeinflusst. Demnach ist anzunehmen, dass

die Ferkel von Sauen, die mit L-Carnitin supplementiert wurden, von Geburt an vitaler sind und möglicherweise aufgrund eines erhöhten L-Carnitinstatus bereits zur Geburt in der Lage sind die Milchdrüsen und somit den Milchfluss stärker zu stimulieren, was letztendlich zu einer verbesserten Entwicklung des Milchdrüsengewebes der Sauen führt. Möglicherweise säugen Ferkel von mit L-Carnitin behandelten Sauen nicht nur länger sondern auch intensiver. Diese Hypothese müsste jedoch in weiteren Untersuchungen geprüft werden.

Neben einer erhöhten Milchleistung von mit L-Carnitin supplementierten Sauen könnte auch ein veränderter Gehalt an Milchinhaltsstoffen ursächlich für eine verbesserte Nährstoffversorgung und das gesteigerte Wachstum der Ferkel während der Säugeperiode sein. In eigenen Untersuchungen (2.4.) konnte am 10. sowie am 20. Laktationstag in der Milch von mit L-Carnitin behandelten Sauen im Vergleich zur Milch von Kontrollsauen kein Unterschied hinsichtlich der Gehalte an Fett, Protein, Laktose und Energie festgestellt werden. Dies steht in Übereinstimmung mit Untersuchungen von RAMANAU et al. (2004, 2005), in denen die Milch von mit L-Carnitin supplementierten Sauen und unbehandelten Sauen am 11. Laktationstag, in Bezug auf die Fett-, Protein-, Laktose- und Energiekonzentrationen, ebenfalls keine Unterschiede aufwies. Jedoch kann anhand dieser Untersuchungen nicht ausgeschlossen werden, dass eine L-Carnitinsupplementierung von Sauen in der frühen Laktation zu einer veränderten Zusammensetzung der Milch führt. Aus diesem Grund wurde der Einfluss von L-Carnitinsupplementierungen bei Sauen auf die Zusammensetzung und den Gehalt an Inhaltsstoffen im Kolostrum in einer weiteren eigenen Studie (2.4.) geprüft. In dieser konnte festgestellt werden, dass mit L-Carnitin behandelte Sauen im Vergleich zu Kontrollsauen deutlich höhere Gehalte an Protein im Kolostrum aufweisen. Zum Zeitpunkt der Geburt sind die Gehalte an Protein im Kolostrum, infolge eines gesteigerten Immunglobulingehaltes, am höchsten und sinken in den ersten Stunden nach der Geburt stark ab. Aufgrund des extrem raschen Abfalls der Proteinkonzentrationen im Kolostrum der Sauen sind diese nicht als ursächlich für die, in zahlreichen Studien festgestellten, erhöhten Lebendmassezunahmen der Ferkel während der gesamten Säugeperiode (HARMEYER 1993, MUSSER et al. 1999a, EDER et al. 2001, RAMANAU et al. 2002, 2004, 2005) anzusehen. Ein erhöhter Proteingehalt im Kolostrum der Sauen führt jedoch zu einer verbesserten Proteinversorgung der Ferkel direkt nach der Geburt und könnte somit den Ferkeln speziell in den ersten Lebenstagen einen Wachstumsvorteil verschaffen.

Ein erhöhter Gehalt an Protein im Kolostrum der Sauen (2.4.) könnte möglicherweise auch mit einem gesteigerten Gehalt an Immunglobulinen in Beziehung stehen. Der Plazentatyp des Schweins (Placenta epitheliochorialis) verhindert einen diaplazentaren Übergang von Immunglobulinen (TIZARD 1992). Auch durch die verschiedenen Gewebeschichten zwischen der maternalen und fetalen Blutzirkulation wird ein Transfer dieser Antikörper verhindert ROTH 1999). Die Ferkel werden somit ohne Immunschutz geboren und sind direkt nach der Geburt auf eine passive Immunisierung durch Aufnahme einer ausreichenden Menge von Immunglobulinen mit der Kolostralmilch angewiesen (DE PASSILLE et al. 1988). Möglicherweise könnte hinter dem verbesserten postnatalen Wachstum der Ferkel während der Säugezeit auch eine verbesserte Versorgung der Ferkel mit Immunglobulinen zu vermuten sein. Jedoch konnte in einer eigenen

Untersuchung (2.4.) kein erhöhter Gehalt an Immunglobulinen (IgG, IgA, IgM) in der Kolostralmilch von mit L-Carnitin supplementierten Sauen festgestellt werden.

RAMANAU et al. (2004, 2005) stellten in ihren Untersuchungen mit Hilfe der „weigh-suckle-weigh" Methode fest, dass Ferkel von mit L-Carnitin supplementierten Sauen in der Lage sind mehr Sauenmilch aufzunehmen. Zudem konnte in eigenen Untersuchungen (2.3., 2.4.) nachgewiesen werden, dass Ferkel von mit L-Carnitin behandelten Sauen in der frühen Laktationsphase deutlich längere Säugezeiten aufweisen als Ferkel von Kontrollsauen. Da die Dauer der Kolostrumaufnahme die Höhe des Immunglobulinspiegels der Ferkel beeinflusst (KRUSE 1983), könnte eine erhöhte Milchaufnahme der Ferkel, hervorgerufen durch deutlich längere Säugezeiten in der frühen Laktationsphase jedoch tatsächlich zu gesteigerten Konzentrationen an Immunglobulinen im Plasma der Ferkel führen und somit die Vitalität der Ferkel nach der Geburt positiv beeinflussen. Die Wirkung von L-Carnitin auf Vitalitätsparameter der Ferkel nach der Geburt und der Gehalt an Immunglobulinen im Plasma der Ferkel wurden in den vorliegenden Untersuchungen jedoch nicht analysiert. Demnach sind hier weiterführende Untersuchungen notwendig.

Als Ursache des verbesserten postnatalen Ferkelwachstums kann somit ein komplexes Wirkungsgefüge von intrauteriner Entwicklung, Geburtsmasse, Säugeverhalten sowie Vitalität und Kolostrum- bzw. Milchaufnahme der Ferkel diskutiert werden. Es ist jedoch zu vermuten, dass die zur Geburt schwereren und/oder vitaleren Ferkel von mit L-Carnitin behandelten Sauen in der Lage sind das Gesäuge stärker und länger zu massieren, durch längere Säugezeiten eine höhere Menge an Kolostrum aufnehmen und über die damit verbundene Immunglobulinaufnahme einen verbesserten immunologischen Schutz erwerben. Durch eine gesteigerte Säugeaktivität bzw. längere Säugezeiten der Ferkel von mit L-Carnitin behandelten Sauen wird zudem die Milchsynthese der Sau stimuliert. Demnach werden Ferkel von supplementierten Sauen über die Milch mit mehr Nährstoffen und L-Carnitin versorgt und zeichnen sich durch höhere Lebendmassezunahmen während der Säugeperiode aus.

3.6. L-Carnitin und Ferkelwachstum nach dem Absetzen

Ferkel von mit L-Carnitin supplementierten Sauen, die im Vergleich zu Ferkeln von unbehandelten Sauen bereits während der Säugeperiode deutlich höhere Lebendmassezunahmen aufweisen, könnten möglicherweise auch nach dem Absetzen eine gesteigerte Wachstumsleistung aufweisen. Um dieser Fragestellung nachzugehen wurde in einer weiteren Untersuchung (2.1.) die Wachstumsleistung von Ferkeln, deren Muttersauen während der Trächtigkeit 125 mg L-Carnitin pro Tag und während der Laktation 250 mg L-Carnitin pro Tag erhielten und von Ferkeln, welche von Kontrollsauen abstammten, nach dem Absetzen untersucht. Ferkel von mit L-Carnitin behandelten Sauen unterschieden sich nach der Entwöhnung, hinsichtlich der Futteraufnahme, der täglichen Lebendmassezunahme sowie der Futterverwertung, nicht von Ferkeln unbehandelter Sauen. Demzufolge hat eine L-Carnitinsupplementierung von Sauen während der Trächtigkeit und Laktation keinen Einfluss auf die Wachstumsleistung der Ferkel nach dem Absetzen.

Die Fähigkeit zur körpereigenen Biosynthese von L-Carnitin ist bei Neugeborenen nur sehr schwach ausgebildet und entwickelt sich allmählich im Verlauf der ersten Lebenswochen (BORUM 1983). Zudem werden die Ferkel nach dem Absetzen nicht mehr über die Sauenmilch mit L-Carnitin versorgt. Dementsprechend ist ein verbessertes Wachstum der Ferkel durch eine L-Carnitinzulage zum Futter, hervorgerufen durch eine erhöhte CPT-I Aktivität sowie ß-Oxidationsrate von langkettigen Fettsäuren in der Leber, speziell in diesem Lebensabschnitt zu erwarten (PENN et al. 1997, HEO et al. 2000b). Verschiedene Studien, in denen eine Supplementierung des Futters mit L-Carnitin bei früh abgesetzten Ferkeln zu einer verbesserten Wachstumsleistung führte (LI et al. 1999, HEO et al. 2000a), bestätigen diese Annahme. Auch NEWTON und HAYDON (1988) sowie OWEN et al. (1993) zeigten, dass eine hochdosierte Verabreichung von L-Carnitin bei Absetzferkeln deren Wachstumsleistung positiv beeinflusst. Eine Supplementierung des Ferkelfutters mit 30 mg L-Carnitin pro kg Futter führte in einer eigenen Untersuchung (2.1.) zu deutlich höheren täglichen Lebendmassezunahmen der Ferkel während der 35- tägigen Fütterungsperiode. Zudem wiesen Ferkel, deren Futter mit L-Carnitin supplementiert war, eine tendenziell verbesserte Futterverwertung auf (p=0,06). Auch in anderen Untersuchungen führte eine Supplementierung des Ferkelfutters mit L-Carnitin zu einer verbesserten Futterverwertung der Tiere nach dem Absetzen (WEEDEN et al. 1990, OWEN et al. 1996, HEO et al. 2000a), welche auf einen Einfluss des L-Carnitins auf den Fett- und Proteinansatz der Tiere hindeutet. Tatsächlich stellten OWEN und Mitarbeiter (1996, 2001a) fest, dass mit L-Carnitin behandelte Schweine einen geringeren täglichen Fettzuwachs während der Wachstumsphase aufweisen. Auch HEO et al. (2000a) berichteten über eine Verbesserung der N-Retention, eine Steigerung des täglichen Proteinzuwachses sowie geringere Körperfettkonzentrationen bei Tieren mit L-Carnitinzufuhr. Der Anteil an Körperfett und Körperprotein wurde bei den Ferkeln der vorliegenden Studie (2.1.) nicht ermittelt, jedoch könnte die verbesserte Nutzung der aufgenommenen Nährstoffe für die Wachstumsleistung tatsächlich auf einen erhöhten Proteinzuwachs und einen reduzierten Fettansatz zurückzuführen sein. In einer eigenen Untersuchung (2.2.) konnten bei Neugeborenen und Saugferkeln keine Unterschiede hinsichtlich der Körperzusammensetzung der Ferkel von supplementierten und unbehandelten Sauen festgestellt werden. Dies ist jedoch nicht verwunderlich, da in diesem Lebensabschnitt die Bildung von Körperfett ohnehin relativ gering ist. Zudem steigerte eine L-Carnitinsupplementierung des Ferkelfutters in der eigenen Untersuchung (2.1.) die Lebendmassezunahme und die Futterverwertung vorrangig bei leichteren Ferkeln von Jungsauen.

In anderen Untersuchungen mit Absetzferkeln konnte hingegen kein Einfluss einer L-Carnitingabe auf die Wachstumsleistung der Ferkel festgestellt werden (HOFFMAN et al. 1993, OWEN et al. 2001a, 2001b). Diese widersprüchlichen Ergebnisse lassen darauf schließen, dass die Wirkung einer L-Carnitinsupplementierung von einer Vielzahl von Faktoren abhängt. Möglicherweise wird die Wirkung von L-Carnitin auf das Wachstum der Ferkel zusätzlich durch weitere experimentelle Faktoren, wie beispielsweise dem Energie- oder Lysingehalt des Futters, beeinflusst (OWEN et al. 1996, HEO et al. 2000b). Demnach ist ebenfalls zur Wirkung von L-Carnitin bei Absetzferkeln weitere Forschungsarbeit notwendig

4. Schlussfolgerung

Eine L-Carnitinsupplementierung von Sauen während der Trächtigkeit und Laktation führt zu keiner Verbesserung der Wachstumsleistung der Ferkel nach dem Absetzen, unter der Voraussetzung von identischen Anfangsgewichten. Der Zusatz von L-Carnitin zum Futter von Absetzferkeln verbessert jedoch die Wachstumsleistung besonders bei leichten Ferkeln aus den Würfen von Jungsauen. Demnach erscheint der Zusatz von L-Carnitin zum Ferkelfutter speziell bei leichten oder früh abgesetzen Ferkeln sinnvoll.

Ferkel von supplementierten Sauen werden besser mit L-Carnitin versorgt und weisen somit zur Geburt und während der Säugeperiode einen höheren L-Carnitinstatus auf als Ferkel von Kontrollsauen. Die Körperzusammensetzung, speziell der Fett- und Proteinansatz, und der Lipidmetabolismus der Ferkel bleiben in dieser frühen Wachstumsphase von einer L-Carnitinsupplementierung der Sauen unbeeinflusst. Somit ist eine veränderte Körperzusammensetzung der Ferkel nicht als ursächlich für das verbesserte Ferkelwachstum während der Säugeperiode anzusehen.

Ferkel von mit L-Carnitin behandelten Sauen realisieren in der frühen Laktationsphase längere Säugezeiten, nehmen möglicherweise mehr Milch auf und weisen in den ersten Lebenstagen höhere Lebendmassezunahmen auf als Ferkel von Kontrollsauen. Dieser Effekt ist vorrangig auf eine L-Carnitinsupplementierung der Sauen während der Trächtigkeit zurückzuführen und ist unabhängig von einer L-Carnitinzufuhr während der Laktation. Dies impliziert, dass eine L-Carnitinsupplementierung von Sauen bereits während der Trächtigkeit erfolgen sollte, um die Wachstumsleistung der Ferkel während der Säugeperiode zu steigern.

Der Nährstoff- und Energiegehalt in der Milch von mit L-Carnitin behandelten Sauen unterscheidet sich nicht von dem unbehandelter Sauen. Dies zeigt, dass die Zusammensetzung der Milch bzw. der Gehalt an Milchinhaltsstoffen keine bedeutende Rolle in Hinsicht auf das, in vorangegangenen Studien festgestellte verbesserte postnatale Wachstum der Ferkel spielt.

L-Carnitin beeinflusst maßgeblich die reproduktive Leistung von Sauen, speziell die Trächtigkeitsrate und Wurfgewichte. Aufgrund von Literaturdaten kann gemutmaßt werden, dass L-Carnitin die Hypothalamus-Hypophysen-Gonaden-Achse beeinflusst und indirekt die Freisetzung von LH und FSH stimuliert. Diese Hypothese muss in weiteren Untersuchungen geprüft werden.

5. Zusammenfassung

Bisherige Untersuchungen zeigten, dass eine L-Carnitinsupplementierung von Sauen während der Trächtigkeit zu höheren Geburtsgewichten der Ferkel führt. Weiterhin zeichneten sich Ferkel von supplementierten Sauen durch ein verbessertes Wachstum während der Säugeperiode aus als Ferkel von Kontrollsauen. Jedoch wurde bisher nicht untersucht, ob Ferkel von behandelten Sauen im Vergleich zu Ferkeln von nicht behandelten Sauen auch nach dem Absetzen ein besseres Wachstum aufweisen. In anderen Untersuchungen führte eine L-Carnitinsupplementierung des Ferkelfutters nach der Entwöhnung zu einer höheren Wachstumsleistung der Ferkel. Es stellte sich die Frage, ob Ferkel von Sauen, die während der Trächtigkeit und Laktation L-Carnitingaben erhielten auch nach dem Absetzen eine verbesserte Wachstumsrate aufweisen oder ob diese vorrangig durch eine Zulage von L-Carnitin zum Ferkelfutter hervorgerufen wird. Ziel der ersten Studie (2.1.) war es daher, neben dem Effekt einer L-Carnitinsupplementierung des Sauenfutters, auch die Wirkung von L-Carnitinzulagen zum Ferkelfutter auf die Wachstumsleistung der Ferkel nach dem Absetzen zu untersuchen. In 2 Durchgängen wurden Ferkel von Jungsauen (Durchgang 1) und Ferkel aus dem 2. Wurf derselben Sauen (Durchgang 2) in 4 Gruppen so eingeteilt, dass die mittleren Ferkelgewichte innerhalb der Gruppen zu Versuchsbeginn gleich waren. Im 1. Durchgang betrug die mittlere Lebendmasse aller Gruppen 8,5 kg und im 2. Durchgang 12,5 kg. Ferkel von Kontrollsauen und Ferkel von mit L-Carnitin behandelten Sauen (Trächtigkeit: 125 mg L-Carnitin/Tier & Tag; Laktation: 250 mg L-Carnitin/Tier & Tag) erhielten ein adäquates Ferkelfutter ohne und mit L-Carnitinzusatz (Behandlungsgruppe: 30 mg L-Carnitin/ kg Futter) angeboten. Zur Beurteilung der Wachstumsleistung der Ferkel wurde die Entwicklung der Lebendmasse sowie die Merkmale tägliche Lebendmassezunahme, tägliche Futteraufnahme und Futterverwertung berücksichtigt. Das Futter wurde den Tieren während der 35-tägigen Fütterungsperiode *ad libitum* angeboten. Ferkel von mit L-Carnitin behandelten Sauen und Ferkel von Kontrollsauen unterschieden sich hinsichtlich der täglichen Lebendmassezunahme, Futteraufnahme und Futterverwertung nicht voneinander. Eine Supplementierung des Ferkelfutters mit 30 mg L-Carnitin/kg führte jedoch vorrangig im ersten Durchgang zu deutlich höheren Körpermassen der behandelten Ferkel am 35. Tag nach dem Absetzen ($P<0,05$), hervorgerufen durch höhere tägliche Lebendmassezunahmen ($P<0,05$). Die, im Vergleich zu Kontrollferkeln, tendenziell verbesserte Futterverwertung der mit L-Carnitin supplementierten Ferkel des 1. und 2. Durchganges ($P<0,10$) deutet auf eine veränderte Körperzusammensetzung, hinsichtlich eines gesteigerten Proteinansatzes und eines reduzierten Fettansatzes, hin. Insgesamt zeigt diese Untersuchung, dass der Einsatz von L-Carnitin in der Ferkelaufzucht, speziell bei leichten Ferkeln aus den Würfen von Jungsauen, einen Nutzen hinsichtlich einer verbesserten Wachstumsleistung erbringt. Eine L-Carnitinsupplementierung der Sauen während der Trächtigkeit und Laktation beeinflusst die Wachstumsleistung der Ferkel nach dem Absetzen, unter der Voraussetzung von identischen Anfangsgewichten der Ferkel, jedoch nicht.

In bisherigen Untersuchungen konnte gezeigt werden, dass eine L-Carnitinsupplementierung von Sauen während der Trächtigkeit und Laktation neben erhöhten Geburtsgewichten der Ferkel und Würfe auch gesteigerte Lebendmassezunahmen der Ferkel während der Säugeperiode zur Folge hat. Bislang sind die Gründe für dieses verbesserte prä- und postnatale Wachstum der Ferkel jedoch nicht vollends geklärt. Möglicherweise könnte der Wachstumsvorteil der Ferkel von mit L-Carnitin behandelten Sauen auf eine günstigere Körperzusammensetzung bereits zur Geburt zurückzuführen sein. Bisher wurde jedoch nicht untersucht, ob Ferkel von supplementierten Sauen eine veränderte Körperzusammensetzung aufweisen oder sich, in Bezug auf metabolische Parameter, von Kontrollferkeln zur Geburt und während der Säugeperiode unterscheiden. Zudem existieren Untersuchungen, in denen eine L-Carnitinsupplementierung bei Absetzferkeln und Mastschweinen, als Folge einer gesteigerten Rate der ß-Oxidation aufgrund einer erhöhten CPT-1 Aktivität, tatsächlich zu geringeren Gehalten an Körperfett im Ganzkörper führt. Das Ziel der zweiten Studie (2.2.) war es daher zu untersuchen, ob eine Supplementierung von Sauen während der Trächtigkeit und Laktation zu Veränderungen der Körperzusammensetzung sowie des Lipidmetabolismus von neugeborenen Ferkeln und Saugferkeln führt. Hierfür wurde ein Versuch mit insgesamt 27 Jungsauen der Rasse (Deutsches Edelschwein x Deutsche Landrasse) durchgeführt, welche unter Berücksichtigung der Lebendmasse und des Alters in eine Versuchsgruppe (n=14) und eine Kontrollgruppe (n=13) eingeteilt und mit Pietrain Ebersperma besamt wurden. Allen Sauen wurde während der Trächtigkeit und Laktation jeweils ein handelsübliches Futter mit geringen nativem L-Carnitingehalt angeboten (Trächtigkeitsfutter: 10 mg/kg; Laktationsfutter: 3 mg/kg). Den Sauen der Versuchsgruppe wurde zusätzlich zur Basisdiät während der Trächtigkeit 125 mg L-Carnitin pro Tier und Tag und während der Laktation 250 mg L-Carnitin pro Tier und Tag verabreicht. Für die Analyse der Körperzusammensetzung wurde jeweils zur Geburt, am 10. sowie am 20. Lebenstag aus jedem Wurf ein Ferkel entnommen, welches dem mittleren Ferkelgewicht des jeweiligen Wurfes entsprach. Da L-Carnitin im Lipidstoffwechsel involviert ist wurden ferner metabolische Parameter wie die Konzentrationen an Triglyceriden, Cholesterol und freien Fettsäuren in der Leber und dem Plasma der Ferkel zur Geburt und während der Säugeperiode bestimmt. Mit L-Carnitin supplementierte Sauen wiesen während der Trächtigkeit eine höhere Futteraufnahme ($P<0,05$) sowie gesteigerte Konzentrationen an insulin-like growth factor-1 (IGF-1) im Plasma am 80. Trächtigkeitstag ($P<0,05$) auf. Hinsichtlich der Anzahl an insgesamt geborenen und lebend geborenen Ferkeln konnten keine Unterschiede zwischen den beiden Behandlungsgruppen festgestellt werden, jedoch wiesen Sauen, die während der Trächtigkeit L-Carnitingaben erhielten, zur Geburt deutlich weniger tot geborene Ferkel auf als unbehandelte Sauen ($P<0,05$). Weiterhin zeichneten sich Ferkel von mit L-Carnitin behandelten Sauen im Vergleich zu Kontrollferkeln durch deutlich höhere Konzentrationen an Carnitin im Ganzkörper und im Plasma sowohl bereits zur Geburt als auch am 10. und 20. Lebenstag aus ($P<0,05$). Hinsichtlich der chemischen Zusammensetzung (Gehalte an Rohfett, Rohprotein und Rohasche) der Ferkelkörper sowie der Plasmakonzentrationen wichtiger Wachstumsfaktoren wie IGF-1 und Insulin, konnten zwischen Ferkeln von Kontrollsauen und Ferkeln von mit L-Carnitin supplementierten Sauen weder zur Geburt noch am 10. oder 20. Lebenstag Differenzen

festgestellt werden. Auch die Konzentrationen an Lipiden (Triglyceride, Cholesterol) im Plasma und der Leber der Ferkel sowie de Gehalte an freien Fettsäuren im Ferkelplasma zur Geburt, am 10. und am 20. Lebenstag blieben von einer L-Carnitinsupplementierung der Sauen während der Trächtigkeit und Laktation unbeeinflusst. Insgesamt zeigt die zweite Untersuchung, dass Ferkel von supplementierten Sauen besser mit L-Carnitin versorgt werden und somit zur Geburt und während der Säugeperiode einen verbesserten L-Carnitinstatus aufweisen als Ferkel von Kontrollsauen. Die Körperzusammensetzung, speziell der Fett- und Proteinansatz, und der Lipidmetabolismus der Ferkel blieben jedoch in dieser frühen Wachstumsphase von einer L-Carnitinsupplementierung der Sauen unbeeinflusst. Veränderungen in der Körperzusammensetzung, also im Ansatz an Fett und Protein, scheinen für das schnellere Wachstum der Ferkel von supplementierten Sauen demnach keine Rolle zu spielen.

Bereits in früheren Untersuchungen wurde gezeigt, dass eine L-Carnitinsupplementierung von Sauen zu einer gesteigerten Milchproduktion und somit zu einem verbesserten Wachstum der Ferkel während der Säugezeit führt. Es ist bekannt, dass das Säugeverhalten der Ferkel ein wichtiger Faktor ist, der die Milchproduktion der Sau und somit das Wachstum der Ferkel während der Säugezeit beeinflusst. Um zu untersuchen, ob die verbesserte Milchleistung der Sauen und das gesteigerte postnatale Wachstum der Ferkel mit einem veränderten Säugeverhalten der Ferkel zusammen hängt, wurde eine dritte Studie (2.3.) mit 2 Experimenten durchgeführt. Die Sauen wurden in eine Versuchsgruppe und eine Kontrollgruppe zu jeweils 13 Tieren (Experiment 1) bzw. zu jeweils 10 Tieren (Experiment 2) eingeteilt und mit handelsüblichem Futter gefüttert. Die Sauen der Versuchsgruppe erhielten wie in den vorangegangenen Untersuchungen während der Trächtigkeit 125 mg L-Carnitin pro Tier und Tag und während der Laktation 250 mg L-Carnitin pro Tier und Tag oral verabreicht. Nach der Geburt wurden alle Würfe auf 11 Ferkel (Experiment 1) bzw. 9 Ferkel (Experiment 2) pro Wurf standardisiert. Im Experiment 1 wiesen die Ferkel von mit L-Carnitin behandelten Sauen am 3., 6. und 9. Laktationstag deutlich längere Säugezeiten und höhere Lebendmassezunahmen während der gesamten Säugeperiode auf als Ferkel von Kontrollsauen ($P<0,05$). Dieser Effekt könnte jedoch durch einen pränatalen oder postnatalen Einfluss von L-Carnitin hervorgerufen werden. Eine L-Carnitinsupplementierung von Sauen während der Trächtigkeit könnte die pränatale Entwicklung der Ferkel verbessern und somit möglicherweise zu einer gesteigerten Vitalität der Ferkel bereits zur Geburt führen, welche eine verlängerten Säugedauer mit sich bringt. Andererseits nehmen die Ferkel von supplementierten Sauen über die Sauenmilch deutlich höhere Mengen an L-Carnitin auf und zeichnen sich somit durch einen höheren Carnitinstatus nach der Geburt und während der Säugeperiode aus als Kontrollferkel, wodurch sie möglicherweise in der Lage sind eine längere Säugedauer zu realisieren. Um zu überprüfen, ob das verbesserte Säugeverhalten der Ferkel von mit L-Carnitin behandelten Sauen vorrangig auf pränatale oder postnatale Effekte des L-Carnitins zurückzuführen ist, wurde ein zweites Experiment durchgeführt, in dem alle Sauen nach der Geburt Würfe von anderen Sauen erhielten. Die Hälfte der Kontrollsauen und die Hälfte der Versuchssauen erhielten Würfe welche von Kontrollsauen geboren wurden, die andere Hälfte der Sauen aus jeder Gruppe

säugten Ferkel, welche von supplementierten Sauen abstammten. Ferkel, welche von mit L-Carnitin behandelten Sauen geboren wurden, wiesen am 3. Lebenstag eine deutlich längere Säugezeit sowie höhere Lebendmassezunahmen während der ersten 14 Lebenstage auf ($P<0,05$). Insgesamt zeigt die Untersuchung, dass eine L-Carnitinsupplementierung von Sauen während der Trächtigkeit den L-Carnitinstatus der Ferkel zur Geburt verbessert. Nach der Geburt sind Ferkel, welche von mit L-Carnitin behandelten Sauen geboren wurden, in der Lage deutlich längere Säugezeiten zu realisieren, wodurch sie möglicherweise mehr Milch aufnehmen und sich demnach durch ein gesteigertes Wachstum während der Säugezeit auszeichnen. Weiterhin zeigt die Untersuchung, dass die Wirkung von L-Carnitin auf das postnatale Wachstum der Ferkel vorrangig auf pränatale Effekte während der Trächtigkeit und weniger auf postnatale Effekte während der Laktation zurückzuführen ist.

Das Wachstum von Ferkeln während der Säugeperiode wird maßgeblich von der Milchleistung der Sau sowie der Energie- und Nährstoffaufnahme der Ferkel über die Sauenmilch bestimmt. Neben einer erhöhten Milchleistung von mit L-Carnitin supplementierten Sauen könnte auch ein veränderter Gehalt an Milchinhaltsstoffen ursächlich für eine verbesserte Nährstoffversorgung und das gesteigerte Wachstum der Ferkel während der Säugeperiode sein. Aus diesem Grund wurde zusätzlich die Milchzusammensetzung von behandelten und unbehandelten Sauen bestimmt. Zudem spielt das Kolostrum für das Überleben, die Vitalität und das Wachstum der Ferkel in den ersten Lebenstagen eine entscheidende Rolle. Ob eine L-Carnitinsupplementierung von Sauen zu Veränderungen in der Zusammensetzung des Kolostrums, speziell im Immunglobulingehalt, führt wurde bisher nicht untersucht. Deshalb wurde in einer weiteren Studie (2.4.) die Wirkung von L-Carnitinsupplementierungen bei Sauen auf die Milchinhaltsstoffe sowie die Zusammensetzung des Kolostrums untersucht. Milchproben von 13 Kontrollsauen und 14 mit L-Carnitin supplementierten Sauen (Trächtigkeit: 125 mg L-Carnitin/Tier & Tag; Laktation: 250 mg L-Carnitin/Tier & Tag) wurden 5-8 Stunden nach der Geburt (Kolostrum) sowie am 10. und 20. Laktationstag gewonnen. Die L-Carnitinsupplementierung hatte keinen Effekt auf die Konzentrationen an Fett, Laktose und den Energiegehalt der Milch beider Gruppen am 10. und 20. Laktationstag. Sauen, die während der Trächtigkeit zusätzlich mit L-Carnitin versorgt wurden wiesen im Kolostrum deutlich höhere Konzentrationen an Protein auf als Kontrollsauen ($P<0,05$). Die Konzentrationen an Fett, Laktose, Immunglobulinen G, M, und A als auch der Energiegehalt im Kolostrum wiesen keine Unterschiede zwischen den Gruppen auf. Insgesamt zeigen diese Ergebnisse, dass die Zusammensetzung der Milch bzw. der Gehalt an Milchinhaltsstoffen keine bedeutende Rolle in Hinsicht auf das, in vorangegangenen Studien festgestellte verbesserte postnatale Wachstum der Ferkel von supplementierten Sauen spielen dürfte. Zusätzlich wurde in dieser Studie (2.4.) das Säugeverhalten der Ferkel mittels Videoaufzeichnungen untersucht. Die in der vorangegangenen Studie (2.3.) festgestellten längeren Säugezeiten der Ferkel von mit L-Carnitin behandelten Sauen konnten bestätigt werden.

Weiterhin zeigten bisherige Studien, dass eine Supplementierung von Sauen mit L-Carnitin zu einer verbesserten Reproduktionsleistung führt. Beispielsweise zeichnen sich mit L-Carnitin behandelte Sauen durch höhere Wurf- und Ferkelgewichte zur Geburt aus. Neben der Anzahl und dem Gewicht der Ferkel zur Geburt und dem postnatalen Wachstum der Ferkel ist die Trächtigkeitsrate bzw. die Anzahl an besamten Sauen, die tragend werden, von besonderer ökonomischer Bedeutung in der Schweineproduktion. Bislang wurde die Wirkung von L-Carnitin auf die Trächtigkeitsrate von Sauen jedoch nicht untersucht. In einer fünften Studie (2.5.) wurden daher drei Experimente zusammengefasst, um den Effekt von L-Carnitin auf die Trächtigkeitsrate, die Wurfgröße und die Wurfgewichte anhand einer hohen Tieranzahl zu überprüfen. Alle drei Experimente wurden mit Sauen durchgeführt, die während der Trächtigkeit und Laktation handelsübliches Futter erhielten. Die Sauen der Versuchsgruppe erhielten zusätzlich pro Tier und Tag 125 mg L-Carnitin während der Trächtigkeit und 250 mg L-Carnitin während der Laktation. Alle drei Experimente erstreckten sich jeweils über drei aufeinander folgende Reproduktionszyklen und wiesen den gleichen Versuchsaufbau auf. Insgesamt wurden in der Kontrollgruppe 93 Sauen und in der Versuchsgruppe 111 Sauen tragend. Die Futteraufnahme der Sauen während der Trächtigkeit sowie die Lebendmassen und die Rückenspeckdicken der Sauen unterschieden sich zu Versuchsbeginn sowie am Ende der Trächtigkeit zwischen beiden Gruppen nicht. Die mit L-Carnitin supplementierten Sauen wiesen jedoch, im Vergleich zu Kontrollsauen, eine deutlich höhere Trächtigkeitsrate (85 vs. 74%, $P<0,05$) und schwerere Würfe zur Geburt (14,4 vs. 13,8 kg/Wurf, $P<0,05$) auf. Insgesamt bestätigt die fünfte Studie, dass eine L-Carnitinsupplementierung die reproduktive Leistung von Sauen maßgeblich beeinflusst. Zudem zeigt die Untersuchung erstmals, dass L-Carnitin die Trächtigkeitsrate von Sauen steigert.

6. Summary

Previous studies showed that supplementation of sows' diets with L-carnitine increases body weights of their piglets at birth. Furthermore, piglets of sows treated with L-carnitine indeed grew faster during the suckling period than piglets of untreated control sows. Until now, it has not been investigated whether piglets of L-carnitine treated sows have a higher growth performance after weaning than piglets of control sows. Some other previous studies demonstrated that L-carnitine supplementation of piglets' diet after weaning improves the growth performance of these piglets. We intended to find out whether piglets of sows supplemented with L-carnitine have a higher growth rate after weaning than those of control sows, and whether this effect is influenced by dietary L-carnitine supplementation of piglets' diet. Therefore, the first study (2.1.) was performed to investigate whether piglets of sows treated with L-carnitine differ in their growth potential from that of piglets of untreated control sows after weaning. It was also investigated whether supplementation of piglets' diets with L-carnitine improves their growth after weaning. In two trials, piglets of the first litters of primiparous sows (trial 1) and the second litters of the same sows (trial 2) were divided into four groups: group 1, piglets of control sows, fed a control diet; group 2, piglets of control sows fed a diet supplemented with 30 mg L-carnitine/kg; group 3, piglets of L-carnitine treated sows, fed a control diet; group 4, piglets of L-carnitine treated sows fed a diet supplemented with 30 mg L-carnitine/kg. Mean initial body weights of the piglets of the four groups were identical. They were 8.5 kg in trial 1 and 12.5 kg in trial 2. To assess growth performance of the piglets we determined body weight gains, feed intake and gain : feed ratios of the piglets. Diets were fed *ad libitum* over a period of 35 days. Piglets from sows treated with L-carnitine did not differ in body weight gains, feed intake and gain : feed ratio from those of control sows. Piglets supplemented with L-carnitine had higher body weight gains ($P<0.05$) and shows therefore a higher body weight at day 35 after weaning ($P<0.05$), particularly in trial 1. In trial 2, no significant difference in these parameters emerged between piglets fed the diet supplemented with L-carnitine and those fed the control diet. There was a tendency towards a higher gain : feed ratio ($P<0.10$) of piglets supplemented with L-carnitine, which could be due to an increased protein accretion and a reduced fat deposition in the body. In conclusion, this study shows that dietary L-carnitine treatment of sows does not improve the growth potential of their piglets after weaning under the conditions of equal initial body weights. The study also shows that L-carnitine supplementation of their diets improves the growth performance particularly in light piglets of primiparous sows.

Recent studies showed that dietary L-carnitine supplementation of sows during pregnancy increases birth weights of piglets and their body weight gain during the suckling period. Until now, the reasons for this increased pre- and postnatal growth of piglets are unknown, but possibly attributed to a different body composition at birth which leads to a higher growth capacity. It has not yet been investigated whether piglets of sows supplemented with L-carnitine differ in their body composition or metabolic parameters from those of control sows at birth and during the suckling period. Moreover there are observations in weaned piglets and growing pigs in which L-carnitine

supplementation leads to a lower content of lipids in the whole body as a result of increased rate of ß-oxidation by risen activity of carnitine palmitoyltransferase I (CPT-1). Therefore, the aim of the second study (2.2.) was to find out whether L-carnitine supplementation of sows during pregnancy and lactation could lead to alterations in body composition and lipid metabolism in their piglets at birth and during suckling period. For this a total of 27 crossbred gilts (German land race x Large white) were allotted to a treatment (n=14) and a control group (n=13) and inseminated with sperm from Pietrain boars. All sows were fed commercially available diets with low carnitine concentrations (gestation diet: 10mg/kg; lactation diet: 3mg/kg). Sows of the treatment group received per day additionally 125 mg of L-carnitine during pregnancy and 250 mg of L-carnitine during lactation. From each litter an average weighted piglet was killed on the 1st, the 10th and the 20th day of life to determine the carcass composition. Because L-carnitine is involved in the lipid metabolism, metabolic parameters, i.e. concentrations of triglycerides, cholesterol and free fatty acids in liver and plasma of the newborn and suckling piglets, were also determined. L-carnitine treated sows had a higher feed intake during pregnancy ($P<0.05$) and higher plasma concentrations of insulin-like growth factor-1 (IGF-1) on day 80 of pregnancy than control sows ($P<0.05$). The number of piglets born was not different between the two groups of sows, but L-carnitine treated sows had fewer stillborn piglets ($P<0.05$). Piglets of L-carnitine treated sows had higher concentrations of L-carnitine in plasma and carcass at birth and on days 10 and 20 of age than control piglets ($P<0.05$). Chemical composition (concentrations of total lipids, protein and ash) of the carcass and plasma concentrations of IGF-1 and insulin, which are important modulators of growth, did not show any difference between the two groups of piglets at birth and on days 10 and 20 of life. Concentrations of lipids (triacylglycerols, cholesterol) in liver and plasma and concentration free fatty acids in plasma were also broadly similar between the two groups of piglets at birth and on days 10 and 20 of life. In conclusion, this study shows that piglets of sows treated with L-carnitine are provided with more L-carnitine and have therefore a better carnitine status at birth and during suckling than piglets of control sows. Their body composition, i.e. deposition of fat and protein, and their lipid metabolism in this early phase of growth are not influenced by supplementation of sows with L-carnitine. Probably the increased postnatal growth of piglets is not caused by a different body composition, but may be the result of increased milk consumption.

It has been shown that L-carnitine supplementation of sows increases their milk production and postnatal growth of the suckling piglets. To test the hypothesis that this effect is due to an improved suckling behaviour of their piglets, a third (2.3.) study, including two experiments with sows, was performed. Two groups of 13 or 10 sows each (in Experiments 1 and 2, respectively) were fed diets with or without supplemental L-carnitine during pregnancy (125 mg/d) and lactation (250 mg/d). After birth, litters of all sows were standardized to equal sizes of 11 and 9 piglets per litter in Experiments 1 and 2, respectively. In Experiment 1, piglets of L-carnitine supplemented sows had a higher total suckling time per day on days 3, 6 and 9 of life and heavier weight gains during suckling period than piglets of control sows ($P<0.05$). This effect could be either due to prenatal or to postnatal effects of L-carnitine. L-carnitine supplementation of sows during pregnancy could

have improved the prenatal development of the piglets which increased their vitality at birth and their suckling persistency. Alternatively, it could be that piglets of sows supplemented with L-carnitine during lactation were able to suckle for longer time because they received more L-carnitine with the milk which might have increased their carnitine status after birth. To clarify whether the improved suckling behaviour of the piglets was due to pre- or postnatal effects of L-carnitine, we performed the second experiment, in which all litters were taken away from their mothers and switched to other sows. Half of the control sows and half of the L-carnitine supplemented sows were given litters born to control sows, the other half of each group was given litters born to L-carnitine supplemented sows. Piglets born to L-carnitine supplemented sows had a higher total suckling time per day on day 3 and heavier body weight gains during the first 14 days than piglets born to control sows ($P<0.05$). In conclusion, the experiments show that supplementation of sows with L-carnitine during pregnancy improves the L-carnitine status of their piglets at birth. Postnatally, piglets born from L-carnitine treated sows are able to suckle longer and probably obtain more milk from the sow and therefore grow faster than piglets born to control sows. Furthermore, this study suggests that beneficial effects of L-carnitine on postnatal growth of piglets are due rather to prenatal effects during pregnancy than on postnatal effects during lactation.

The growth of piglets during suckling periods depends on the piglets' intake of energy and nutrients from sows' milk. An increased intake of nutrients of piglets which leads to higher postnatal growth rates could be due, besides an increased amount of milk, also to an altered composition of the milk, i.e. increased concentrations of nutrients and energy. Therefore, in a further study (2.4.), the composition of the milk of sows supplemented with L-carnitine was determined to find out whether an altered milk composition could account for the increased growth rates of the piglets. Moreover, for survival, vitality and growth during the first days of life, the colostrum plays an important role. Whether L-carnitine supplementation in sows alters the composition of the colostrums, i.e. concentrations of immunoglobulines, has not yet been investigated. Therefore, in this study we investigated the effect of L-carnitine on the milk, including concentrations of immunoglobulines in the colostrum. Milk of 13 control sows and 14 sows supplemented with L-carnitine (125 mg/d during pregnancy, 250 mg/d during lactation) was collected 5-8 hours after birth (colostrum) and on days 10 and 20 of lactation. Concentrations of fat and lactose and the energy content did not differ between both groups of sows in milk of days 10 and 20. Sows supplemented with L-carnitine had a higher concentration of protein in colostrum ($p<0.05$) while concentrations of fat, lactose, immunoglobulines G, M and A as well as the energy content in colostrum did not differ between both groups of sows. In conclusion, these findings show that milk composition does not play a major role for the increased postnatal growth of piglets from sows supplemented with L-carnitine observed in recent studies.

Furthermore, previous studies have shown that supplementation of sows with L-carnitine increases their reproductive performance. Sows supplemented with L-carnitine had higher piglet and litter weights at birth. Besides number and weights of piglets at birth and postnatal growth of the piglets,

the number of sows which become pregnant is an important parameter in practical pig production. To our knowledge, the effect of L-carnitine on the pregnancy rate in sows has not yet been investigated. In the fifth study (2.5.) we therefore evaluated three sow experiments to determine the effect of L-carnitine on the pregnancy rate, litter sizes and litter weights in sows. All three experiments were performed with gilts which received nutritionally adequate diets during pregnancy and lactation. The treated sows received 125 mg L-carnitine/day during pregnancy and 250 mg L-carnitine/day during lactation; control sows did not receive L-carnitine. All three experiments were performed over three consecutive reproductive cycles and were similar in conductance. Total number of pregnancies evaluated was 93 in the control group and 111 in the L-carnitine treated group. Feed intake during pregnancy as well as body weights and backfat thicknesses at the beginning and the end of pregnancy did not differ between both groups of sows. However, sows supplemented with L-carnitine had a higher pregnancy rate (85 vs. 74%, $P<0.05$) and heavier litters at birth (14.4 vs. 13.8 kg/litter, $P<0.05$) than control sows. There was also a tendency towards a higher number of piglets born alive per litter in sows supplemented with L-carnitine than in control sows (11.9 vs. 11.0, $P=0.07$). In conclusion, this study confirms that L-carnitine supplementation has beneficial effects on the reproductive performance of sows. In particular, it is shown for the first time that L-carnitine increases the pregnancy rate in sows.

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Ich erkläre hiermit an Eides statt, dass ich die vorliegende Dissertation **„Experimentelle *Untersuchungen zur Wirkung von L–Carnitinsupplementierungen bei Sauen und deren Ferkeln*“** selbständig und nur unter Verwendung der angegebenen Literatur und Hilfsmittel angefertigt habe. Die Arbeit wurde bisher in gleicher oder ähnlicher Form keiner anderen Prüfungsbehörde vorgelegt.
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