Bioactive substances in meat and meat products

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In addition to the customary vital nutrients, meat and meat products also contain additional, physiologically active components that can promote human health. These include L-carnitine, coenzyme Q_{10}, carnosine, anserine, taurine, creatine, glutathione, lipoic acid, conjugated linoleic acid (CLA) and bioactive peptides. The following article presents a brief overview of these bioactive substances.

In the 20th century it was assumed that alongside water, food was made up of carbohydrates, proteins, fats, minerals and vitamins, as well as fibres and antinutritive ingredients. For a long time this assumption dominated nutritional thinking. However, improved detection methods for substances and their modes of action in foods and in the human body have led to changes in the way many antinutritive ingredients are assessed. Given the wealth of protective effects demonstrated by these substances, the term antinutritive ingredients has been changed into bioactive substances. These are understood to be health promoting active ingredients in foods without a nutrient character. Essential nutrients are substances that are vital for humans, but which humans cannot synthesise themselves, or not in sufficient quantities (e.g. vitamins, minerals, some amino and fatty acids). Bioactive substances, on the other hand, are not vital – but they complement the effect of the nutrients (Watzl and Leitzmann, 1995).

When bioactive substances are discussed, the talk is chiefly of secondary plant materials such as e.g. phytosterins, carotenoids, terpenes, polyphenols, or also substances in fermented foods such as e.g. bioactive peptides. Meat and meat products on the other hand are not perceived as sources of bioactive substances, but instead “only” as suppliers of high-grade protein and many vitamins and minerals. Yet research has made progress in the meat segment too and today in particular L-carnitine, coenzyme Q_{10}, carnosine, anserine, taurine, creatine, glutathione, lipoic acid, conjugated linoleic acid (CLA) and bioactive peptides are a focus of discussion. These bioactive substances in meat and meat products are presented below.

L-carnitine

L-carnitine was first isolated from meat extract in 1905. However, it took a further 50 years before its chemical structure was verified (Fig. 1). Relatively soon after this its physiological functions in the human body became known (Pittner et al., 2005). L-carnitine (γ-trimethylamino-β-hydroxy butyric acid) is a small molecule that is found in nearly all cells.

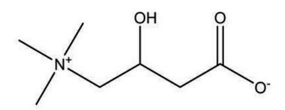

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Fig. 1: Structure of L-carnitine

▶ Function

L-carnitine plays a key role in human fat metabolism. Long-chained fatty acids are broken down in muscle and liver cells to obtain energy (β-oxidation). For this purpose the free fatty acids have to be carried into the mitochondria of the cells. L-carnitine is an integral component of the special transport mechanism needed for this. The fatty acids are carried through the inner mitochondria membrane as L-carnitine ester. That is why an L-carnitine deficit impairs the oxidation of long-chained fatty acids in the mitochondria (Luppa, 2004; Rehner and Daniel, 1999). On the grounds of its function L-carnitine is frequently recommended as a food supplement for boosting ‘fat combustion’, chiefly within the context of weight reduction diets and in the world of sports to enhance performance. However, this only appears promising where the body’s L-carnitine concentration is low due to insufficient intake, increased losses or genetic damage. That is why most people cannot expect performance enhancement in sports or weight reduction simply by increasing their intake of L-carnitine (Galloway and Broad, 2005; Luppa, 2004; Brass, 2000). Restricted fatty acid oxidation due to an L-carnitine deficit might possibly result in an energy deficit that can lead to severe health impairments, especially at the cardiac muscle (Luppa, 2004). Studies with old rats have shown that supplementing diets with L-carnitine can have a positive influence on age-dependent memory decline and learning capacity, and the attentiveness and concentration of Alzheimer’s patients has also been improved with acetyl-L-carnitine (Lohninger et al., 2005; Rebouche, 1992). However, L-carnitine intake in pharmacological doses is necessary to achieve this.

Tab. 1: Content of L-carnitine in various foods (mg/100 g fresh weight)

	L-carnitine (mg/100 g)
Beef steak	65.0
Minced beef	87.5
Chicken breast without skin	10.4
Turkey meat	21.2
Lamb chop	40.5
Pork shoulder	21.1
Ham	33.5
Veal shoulder	78.2
Merguez (beef sausage with lamb)	66.3
Pork sausage	7.1
Tuna fish	1.5
Smoked salmon	1.0
Milk (2% fat)	2.9
Gruyère cheese	6.5
Mozzarella	0.3
Yoghurt	12.2
Quark (curd cheese)	1.8
Apple	0.2
Carrot	0.3
Avocado	8.1
Onion	0.7
Potato	2.4

Source: Demarquoy et al. (2004)
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▶ Occurrence and intake quantities

The human organism, like the organisms of mammals, synthesises L-carnitine from the two essential amino acids lysine and methionine, chiefly in the liver, kidneys and brain. Other tissues have to absorb L-carnitine from the blood circulation (Arihara, 2006; Lohninger et al., 2005). Only about 25% of the L-carnitine is produced by the organism itself, and in the case of humans about 75% of the body pool is obtained from food. About 65 to 75% of the L-carnitine occurring in food is absorbed in the small intestine and the rest is then mainly degraded by microorgan-

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isms in the large intestine. A small portion is eliminated with the stools. The L-carnitine level in the blood is regulated via the kidneys and depends on age and gender. L-carnitine is eliminated via the kidneys and bile (Lohninger et al., 2005; Vaz and Wanders, 2002).

For humans, meat is the main source of L-carnitine. Calculations by Demarquoy et al. (2004) based on consumption data from France revealed a daily L-carnitine intake of on average 76.5 mg (472 µmol), of which 77.8% comes from meat and meat products, and 14.4% from dairy products and eggs. Vegetarians ingest on average 16.3 mg and vegans only 3.6 mg L-carnitine per day. L-carnitine is chiefly found in red meat, fish and dairy products (Tab. 1). With few exceptions, plant foods on the other hand contain only slight quantities of L-carnitine (Demarquoy et al., 2004). Animal tissue has between 40 and 540 µmol (or between 6.5 and 87.5 mg) L-carnitine per 100 g, with beef and veal showing higher contents than pork, lamb and poultry meat (Rigault et al., 2008; Demarquoy et al., 2004). Rigault et al. (2008) found between 369 and 465 µmol per 100 g in various pieces of fresh beef. Neither heating the meat (cooking, grilling, baking, deep-frying and heating in the microwave) nor freezing (for up to six months) influenced the L-carnitine contents.

Coenzyme Q_{10} (Ubiquinone)

Ubiquinone (2,3-dimethoxy-5-methyl-6-multiprenyl-1,4-benzoquinone) owes its name to the fact that the coenzyme is ubiquitous (present everywhere). Ubiquinone is also known as coenzyme Q. It is a quinone derivative with a lipophilic isoprenoid side chain (Fig. 2). Depending on the number of isoprene units in the side chain, the coenzyme is called Q_1, Q_2, Q_3, etc. In humans as in most mammals (rodents are an exception), Q_{10} prevails (Overvad et al. 1999; Ernster and Dallner, 1995). Coenzyme Q_{10} (CoQ_{10}) was discovered in 1957 by F. Crane and its structure was determined in 1958 by K. Folkers and colleagues. It turned out that CoQ_{10} was identical with ubiquinone that had already been described earlier by the group around R.A. Morton (Crane, 2007; Ernster and Dallner, 1995).

Tab. 2: Content of coenzyme Q_{10} and Q_9 in various foods (mg/100 g fresh weight)

	Q_{10} (mg/ 100 g)	Q_9 (mg/ 100 g)
Ox liver	3.92	0.14
Beef	3.65	0.04
Pig's liver	2.27	0.12
Ham	2.00	0.09
Chicken	1.40	0.04
Egg	0.12	–
Tuna fish	1.59	0.03
Rainbow trout	0.85	0.03
Emmentaler cheese	0.13	–
Milk (1.5% fat)	0.01	–
Yoghurt	0.24	–
Wheat bread	0.21	–
Rye bread	0.47	–
Tomatoes	0.09	–
Carrots	0.17	–
Potatoes	0.05	–
Apple	0.13	0.02
Orange	0.14	–
Rapeseed oil	6.35	–

Source: Mattila and Kumpulainen (2001)
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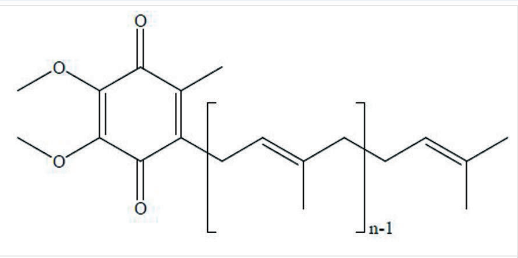

Source: Schmid Fleischwirtschaft International 2/2010

Fig. 2: Structure of Coenzyme Q

▶ Function

The animal/human cell satisfies the major part of its energy requirement by oxidising reduced coenzymes in the mitochondria ("cell powerhouses"), where oxygen serves as an oxidant (respiratory chain phosphorylation). The central function of CoQ_{10} is to transport electrons within this mitochondrial respiratory chain. Electron losses occurring during these operations lead to the largest quantities of oxygen radicals in the organism arising here. Oxygen radicals can damage fats, proteins and DNA. This is known under the name "oxidative stress". In this context CoQ_{10} is considered a very effective antioxidant (Turunen et al., 2004). CoQ_{10} develops its antioxidative effect not only in the mitochondria membrane, but also generally in all cell membranes. Furthermore, it plays an important role in regenerating other antioxidants such as e.g. vitamin E (Crane, 2007 and 2001; Bentinger et al., 2007). CoQ_{10} might possibly also influence the membrane fluidity, the phospholipid metabolism and the expression of various genes, but this still requires further clarification (Pepe et al., 2007; Turunen et al., 2004). Coenzyme Q_{10} is frequently prescribed as a supplement for cardiac muscle weakness in order to improve cardiac function (Turunen et al., 2004). There are also encouraging indications in the case of heart failure and high blood pressure (Pepe et al., 2007; Overvad et al., 1999). Furthermore, animal studies indicate the influence of CoQ_{10} on the ageing process (through reduced oxidative stress), but this is still being discussed controversially (Navas et al. 2007; Sohal and Forster, 2007). CoQ_{10} is also associated with neurodegenerative illnesses such as Huntington and Parkinson (Turunen et al. 2004). Generally the quantity of coenzyme Q_{10} required to achieve a positive effect (>100 mg per day according to Crane, 2001) is quite a bit higher than can be ingested through food.

▶ Occurrence

Coenzyme Q is found in microorganisms, plants, animals and humans. It is localised on the hydrophobic side of the phospholipid double layer of cell membranes. Coenzyme Q_{10} occurs in most human tissues, but in differing concentrations. The highest CoQ_{10} concentrations are found in the heart (110 µg/g tissue), in the liver (60 µg/g) and in the kidneys (70 µg/g). The lowest concentration is found in the lung tissue (8 µg/g). In blood plasma, coenzyme Q_{10} occurs in the range of 0.75 to 1.00 µg/mL. The total content in the body is estimated at 1.0 to 1.5 g, with the muscles accounting for the largest share (Turunen et al., 2004; Overvad et al., 1999). The coenzyme Q_{10} content in the body may possibly decline with increasing age. However, the statements made in human and animal studies on this subject are still insufficiently informative (Sohal and Forster, 2007).

CoQ_{10} appears in most foods, with the highest concentrations being found in meat and fish (Tab. 2). In meat, the bandwidth of CoQ_{10} ranges from about 1.4 to 4.6 mg/100 g (fresh meat and liver), with even higher concentrations in heart (Mattila and Kumpulainen, 2001; Weber et al., 1997; Purchas et al., 2004).

▶ Processing losses

It has not yet been clarified exactly what influence cooking has on the content of coenzyme Q_{10}. Purchas et al. (2004) found a higher concentration of CoQ_{10} in lamb (based on the dry weight) after a cooking time of 90 min. at 70 °C, which they attribute to the fact that CoQ_{10} which was not extractable beforehand may have been made available by the cooking process. A later experiment with beef produced a lower CoQ_{10} concentration after grilling the meat (at 200 °C) (Purchas et al., 2006). Weber et al. (1997) documented a decline of 15 to 32% of CoQ_{10} in pork cutlets due to frying the meat, but no details on the cooking process were supplied.

▶ Absorption quantities and bioavailability

Coenzyme Q_{10} is synthesised by all animals and humans, but is also absorbed from food. A study from Finland showed a total coenzyme Q_{10} intake of 5.4 mg for men and 3.8 mg for women (Mattila and Kumpulainen, 2001). The main source of CoQ_{10} was meat, accounting for 55% of intake. Meat was followed by vegetable fats/oils accounting for 18% (rapeseed oil is a good source), and then fish and dairy products accounting for 9 and 8% respectively (Mattila and Kumpulainen, 2001). A Danish survey produced comparable figures (intake of 3 to 5 mg per day, of which 64% from meat; Weber et al., 1997).

There are no intake recommendations for coenzyme Q_{10}. So far no deficit symptoms have been detected in otherwise healthy persons, from which it can be assumed that a varied mixed diet together with normal synthesis by the organism of a healthy person makes sufficient CoQ_{10} available.

The bioavailability of coenzyme Q_{10} from food appears to be relatively low (about 10%, Weber et al., 1997). Studies with food supplements show great differences in the absorption, depending on dosing and form, but also pronounced differences between individuals (Miles, 2007; Turunen et al., 2004). Supplements of up to 1,200 mg per day for adults and up to 10 mg/kg per day for children are considered safe (Miles, 2007). For a long time it was assumed that external CoQ_{10} is absorbed from the intestine, but only reaches the periphery tissues from the blood (with the exception of the liver) if there is a CoQ_{10} deficit. However, more recent studies indicate that continuous and high administration of coenzyme Q_{10} leads to it being absorbed in the tissue, irrespective of the supply. Further studies, above all also human studies, are necessary however in order to confirm this (Miles, 2007; Sohal and Forster, 2007; Turunen et al., 2004).

Carnosine and anserine

Carnosine (β-alanyl-L-histidine) is a dipeptide from the two amino acids β-alanine and L-histidine (Fig. 3). It was discovered in beef extract at the beginning of the 20th century by W. Gulewitsch and S. Amiradzibi. However, its main function has still not been absolutely clarified (Park et al., 2005; Skulachev, 2000). Anserine (β-alanyl-N-methyl-L-histidine) is an N-methylated derivative of carnosine (Quinn et al., 1992).

▶ Function

Carnosine and anserine play a major role in muscle tissue as pH buffer. A high buffer capacity in the muscle can stabilise the intramuscular pH value and thus enlarge capacity for anaerobic performance and tolerance in the case of oxygen deficit (Abe, 2000). Carnosine and anserine also show antioxidative properties (Guiotto et al., 2005) and can reduce certain proteolytic reactions too. They block the formation of AGEs (Advanced Glycosylation End-products). AGEs are considered to be a risk marker for pathophysiological conditions in age-dependent illnesses. They increase as age progresses as well as with pathological circumstances such as diabetes, cataracts, arteriosclerosis and Alzheimer's disease (Reddy et al., 2005). As both the antioxidative and the AGE-reducing properties of carnosine and anserine are connected with cell ageing, carnosine is often marketed as an "anti-ageing" substance. However, further studies are necessary to be able to make exact statements here. Carnosine and anserine are also able to form complexes with metal ions such as copper, zinc and cobalt. Depending on the metal ion bonded, the complexes display differing biological functions (Baran, 2000). For example the carnosine zinc complex alleviates injuries to the gastric mucosa, acts against stomach ulcers and inhibits their chief pathogen *Helicobacter pylori*, which is why the said complex is also used as a medicine (Baran, 2000; Matsukura and Tanaka, 2000). Carnosine is also found in the central nervous system, although its specific physiological role here has not yet been clarified. It is, however, suspected that it could act as a natural protection factor and as a neurotransmitter (De Marchis et al., 2000).

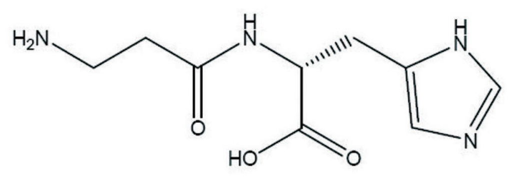

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Fig. 3: Structure of carnosine

▶ Occurrence

Carnosine and anserine are widespread in vertebrate tissue. The largest quantities are found in muscle tissue (the average concentration of carnosine is 20 mmol/kg dry matter in humans), but nerve tissue and the brain also contain relatively large amounts (Guiotto et al., 2005; Quinn et al., 1992; Boldyrev and Severin, 1990). The carnosine concentrations appear to decrease in humans as age progresses (Stuerenburg and Kunze, 1999). Carnosine is synthesised by the organism itself from β-alanine and L-histidine – but is also absorbed through food. Following administration of 4 g carnosine, up to 14% of the dose was detected intact in the urine. The detected quantity depended strongly on the activity of the carnosine-splitting enzyme carnosinase in the plasma, however (Gardner et al., 1991). A more recent study examined the carnosine concentrations in blood plasma following a meal with 200 g minced beef (124 mg carnosine/100 g meat). The carnosine concentration in the plasma reached its highest level (32.7 mg/L) 2.5 hours after consumption before dropping again, and after 5.5 h in the plasma no more carnosine could be detected (Park et al., 2005). However, it has not yet been clarified whether the carnosine from the blood entered the muscle or nerve cells. Anserine in turn is formed by methylating carnosine. (Boldyrev and Severin, 1990).

Carnosine and anserine are only found in meat, poultry and some fish, but not in foods of plant origin. Zapp and Wilson (1938) found carnosine quantities of between 191 and 351 mg/100 g in oxen and anserine quantities of 27 to 144 mg/100 g in various muscles. Purchas et al. (2004) ascertained carnosine contents of 453 mg/100 g in *M. semitendinosus* of cattle, but the quantities in the heart and liver were much lower (32.6 and 77.5 mg/100 g). In lamb, the carnosine values in the *triceps brachii*, *semitendinosus* and *longissimus lumborum* muscles were similar – between 251 and 491 mg/100 g. The carnosine content in pork also displays comparable values. There were quantities of between 211 and 419 mg/100 g in various muscles (Mora et al., 2008). The contents of anserine in beef and pork were below those of carnosine, while in poultry meat higher quantities of anserine are detectable (Abe, 2000; Boldyrev and Severin, 1990).

▶ Use as antioxidant

In meat products carnosine can be used as a natural antioxidant. Various studies show that by adding carnosine, fat oxidation and the formation of metmyoglobin are inhibited, leading to stabilisation of the meat colour and flavour and thus improving storability (Badr, 2007; Das et al., 2006; Djenane et al., 2004; Sánchez-Escalante et al., 2001).

Taurine

Taurine was first isolated from ox bile by the chemists Leopold Gmelin and Friedrich Tiedemann in 1827, giving the substance its name (the Latin word for ox bile is *fel tauri*). Taurine (2-aminoethanesulfonic acid) is a simple, sulphurous amino acid (Fig. 4).

▶ Function

Despite its amino acid structure, taurine is not used in the human body to build proteins (the sulfon group cannot enter into peptide bonds). However, it plays a role in many physiological functions, such as e.g. in bile acid conjugation, development of the retina and the nervous system, osmoregulation, modulation of the calcium level and the immune function (Bouckenooghe et al., 2006). Taurine accounts for the greater part of all free amino acids in the heart. It has an antiarrhythmic effect and a positive inotropic influence on the cardiac muscle. This means that it increases regularity of contraction and the strength of the heart (Bretz, 2002). Taurine is frequently added to "energy drinks" and similar products, accompanied by the claim that it enhances physical and mental capacity. However, there are (as yet) no validated findings for this. So far no effects on concentration, attentiveness or psychomotoric performance have been found (DGE, 2001).

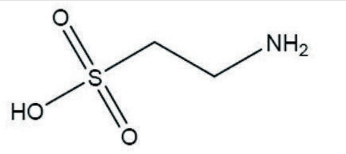

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Fig. 4: Structure of taurine

▶ Occurrence and absorption quantities

Taurine is widespread in animal cells as a free amino acid, but does not occur in plants (except in a few algae and the prickly pear) (Bouckenooghe et al. 2006; Bretz 2002). Concentrations vary very strongly depending on animal species and tissue. A human being with a body weight of 70 kg has about 30 to 70 g taurine, of which about 75% are to be found in muscle cells. Organs with a particularly high taurine content are the skeletal muscles, heart, brain and liver (Bretz, 2002). The taurine present in the human body originates from three sources: 1. intake from food, 2. synthesis from methionine and cysteine in the liver and other tissues, 3. reabsorption in the kidneys. The synthesis of taurine covers needs, but is lower than in other species (e.g. rodents), which is why intake with food and hence the consumption of foods of animal origin also play a certain role (Bouckenooghe et al., 2006; Rana and Sanders, 1986). Vegans do not absorb any taurine with their purely plant nutrition. However, omnivores have a daily intake of between 40 and 400 mg (Shao and Hathcock, 2008; Laidlaw et al., 1990; Rana and Sanders, 1986). The taurine contents of foods are influenced by treatment processes and cooking methods, which must be taken into account when calculating intake (Rana and Sanders, 1986). The taurine content of various foods is listed in Table 3. The highest concentrations are found in seafood (e.g. mussels, calamari) (Laidlaw et al., 1990). Meat and fish also contain relatively large quantities with amounts varying depending on the animal species and piece of meat. The taurine content in lamb lies between 57.3 and 160.6 mg/100 g depending on the muscle analysed (Purchas et al., 2004). Milk and dairy products contain relatively low amounts of taurine by comparison with meat. As already mentioned, with a few exceptions no taurine was detected in plant foods.

Tab. 3: Taurine content (mean and SEM) of various foods (mg/100 g fresh weight)

	Taurine (mg/100 g)
Chicken: light meat	18 ± 3
Chicken: dark meat	169 ± 37
Turkey: light meat	30 ± 7
Turkey: dark meat	306 ± 69
Beef	43 ± 8
Veal	40 ± 13
Pork loin	61 ± 11
Ham	50 ± 6
Salami	59 ± 8
Tuna fish in oil	42 ± 13
Oysters	396 ± 29
Mussels	655 ± 72
Full-fat milk	2.4 ± 0.3
Full-fat natural yoghurt	3.3 ± 0.5
Fruit juices (apple, orange)	–
Vegetables (tomato, broccoli, cucumbers, sweet corn, onions, potatoes, asparagus)	–
Lentils	–
White bread, whole grain bread	–
Oat flakes	–
Nuts (almonds, walnuts, groundnuts)	–
Rice	–
Pasta	–

Source: Laidlaw et al. (1990) Fleischwirtschaft International 2/2010

Conjugated linoleic acid (CLA)

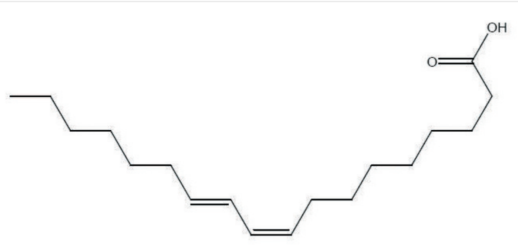
In 1979 Pariza et al. discovered the presence of an antimutagenic substance in hamburgers. A few years later the substance found was identified as conjugated linoleic acid (CLA) (Ha et al., 1987). CLA consists of a group of geometric and positional isomers of linoleic acid (*cis*-9,*cis*-12 18:2). All isomers are characterised by the fact that their two double bonds are connected only by an individual single bond (conjugated) instead of by two of them as usual. The double bonds can lie at different places in the carbon chain and occur in both *trans*- and *cis*-configuration. This makes up to 28 variants (isomers) possible. In nature the largest share (about 80%) of the CLA isomers occurs in the *cis*-9, *trans*-11 form (Fig. 5) (Mulvihill, 2001; Fritsche and Steinhardt, 1998).

▶ Function

In animal studies and cell cultures CLA has revealed various positive health effects. The first health benefit of CLA to be discovered related to an anticarcinogenic effect in the animal model. The examinations were extended to various human cell lines (in vitro studies), where antineoplastic activity (inhibition of the new formation of body tissue) was detected, that could be based on an antiproliferative or pro-apoptotic effect (inhibits the reproduction and promotes cell death respectively) (Li and Watkins, 2007; Kelley et al., 2007). A further well-researched effect is the impact of CLA on body composition. In animal studies it changed the body composition through a reduction of the fat mass with a simultaneous increase in fat-free body mass. In humans the effect was smaller, but with CLA supplements of at least 3.2 g per day over more than 12 weeks, it does appear to exist (Jutzeler van Wijlen, 2007; Whigham et al., 2007; Badinga and Greene, 2006). Research into the effect of CLA on cardio-vascular diseases has not yet been completed. Animal studies revealed a reduction and prevention of arteriosclerotic lesions from the administration CLA. In humans the occurrence of the level of arteriosclerotic lesions cannot be examined directly, which was why human studies have so far concentrated on blood lipids as replacement parameters. The results to date are not consistent, however, and therefore do not allow any conclusions (Bhattacharya et al., 2006). It appears that the two isomers *cis*-9, *trans*-11 and *trans*-10, *cis*-12 have opposite effects. The first isomer acts positively on the LDL-:HDL-cholesterol and/or total:HDL-cholesterin ratio, but the second does not (Tricon et al., 2004). As *cis*-9, *trans*-11 CLA accounts for the main share of the CLA isomers occurring in animal fat, a negative effect in ruminant fat can probably be ruled out. A study by Raff et al. (2008) with butter supports this assumption. Further effects of CLA on the immune system, on bones and in diabetes are assumed, but require more detailed investigation. Altogether it must be noted that in most of these studies CLA was used in quantities that lie much above the concentrations normally absorbed with food.

▶ Occurrence

CLA develops naturally through microbial isomerisation/biohydrogenation of polyunsaturated fatty acids in the rumen of ruminants



Source: Schmid Fleischwirtschaft International 2/2010

Fig. 5: Structure of CLA (*cis*-9, *trans*-11 18:2)

and through desaturation of trans fatty acids (above all vaccenic acid) in the tissue (Griinari and Bauman, 1999). That is why it is to be found chiefly in the fat of ruminants, in other words in meat and milk from these animals and in the products made from them. The amount of CLA in meat varies not only depending on the breed or the cut of meat selected, but is also strongly affected by the feeding of the animals. As a consequence the concentration in beef can lie between 1.2 and 10.0 mg/g fat. In lamb it is mainly somewhat higher, between 4.3 and 19.0 mg/g fat. By comparison the CLA concentrations in pork, horsemeat and chicken are very low, generally below 1 mg/g fat. The levels in meat products are comparable with those in the processed raw material (Schmid et al., 2006).

▶ Quantities absorbed

Humans can synthesise CLA from the vaccenic acid ingested with food (Turpeinen et al., 2002), but also take CLA in directly with the food. Studies in various countries revealed a CLA supply of between 95 and 440 mg per day, with great differences being found not only between countries, but also between individuals. These differences are explained by different eating habits as well as by differing CLA concentrations in the animal products (Schmid et al., 2006).

Creatine

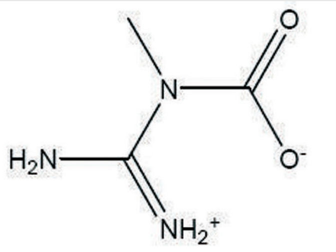
Eugène Chevreul discovered creatine in 1834 as a constituent of meat broth. In 1847 the German chemist Justus von Liebig then detected creatine as a component in meat from various mammal species. The name "creatine" comes from the Greek kreas = meat (Feldman, 1999). In chemical terms, creatine consists of 3-methylguanidino acetic acid (or N-(aminoiminomethyl)-N-methyl-glycine) (Fig. 6).

▶ Function

The physiological significance of creatine lies in the area of energy provision in muscle contraction. Creatine phosphate makes available the phosporyl group that is used to convert the adenosine diphosphate (ADP) resulting from muscle contraction back into adenosine triphosphate (ATP). The hydrolytic splitting of ATP provides the energy for muscle contraction and creatine phosphate represents an energy reserve that can be used quickly. During periods of rest the creatine phosphate reserves are then filled up again (Feldman, 1999).

▶ Supplementing in sports

Creatine is readily used as a food supplement by athletes in order to enhance performance capability. The muscle reserves of creatine can be maintained at a very high level over a long period with high initial doses (10 to 50 g per day) followed by lower doses taken continuously (2 to 5 g per day) or also simply by taking lower doses over a relatively long period. The amount of possible increase is very individual, however (EFSA, 2000 and 2001; König and Berg, 2000). Studies have shown that supplementing creatine can indeed increase muscle power and performance during short periods of maximal activity (anaerobic). Aerobic-oriented activities are not improved, however (EFSA, 2001). In the case of vegetarians or vegans, the effect is often far more distinct than it is among meat and fish eaters, which is presumably due to the diet-related low creatine concentrations often encountered in the muscles of the former group (Barr and Rideout, 2004). However, the effect of creatine supplementation cannot be achieved among athletes purely by meat consumption, as even the lowest doses for enhanced performance capability (2 g per day) lie about four times higher than the maximum concentrations in 100 g meat.



Source: Schmid Fleischwirtschaft International 2/2010

Fig. 6: Structure of creatine

▶ Occurrence and quantities absorbed

Creatine occurs naturally in large quantities in the skeletal muscles and in small quantities in the brain, liver, kidneys and testicles. The entire body pool of creatine in a 70 kg man comprises about 120 g, with 95% of this being found in the muscles (60 to 67% in phosphorylated form) (Feldman, 1999; Greenhaff, 1997; Balsom et al., 1994). The daily creatine turnover in the muscles is about 2 g. About 1 to 2 g creatine per day is eliminated in the form of creatinine via the kidneys. Under normal nutritional conditions, creatine losses are made up in roughly equal parts by the body's own synthesis and by supplies in the food (EFSA, 2000; König and Berg, 2000). In the human organism creatine is mainly synthesised in the liver from the amino acids glycine, arginine and methionine, and subsequently conveyed from there into the muscular tissue (Greenhaff, 1997). The synthesis rate lies at about 1 to 2 g per day. Creatine is also absorbed with food, above all with meat, fish and other products of animal origin. A typical diet contributes about 1 to 2 g creatine a day (EFSA, 2000), but in principle the supply can lie between 0 g for purely plant

Tab. 4: Contents of glutathione (GSH and GSSG) and cysteine in various foods (mg/100 g fresh weight)

	Glutathione (mg/100 g)		Cysteine (mg/100 g)
	GSH	GSSG	
Beef steak	12.3	13.4	279
Ox liver	0.8	2.5	410
Pork chop	18.9	23.6	350
Chicken breast	6.5	13.1	348
Ham	13.7	23.3	298
Frankfurters	2.4	6.2	130
Tuna fish (in oil)	1.1	1.6	172
White bread	0	0	174
Whole grain bread	0	1.2	178
Egg	0	0	278
Yoghurt	0	0	40
Full-fat milk	0	0	30
Spinach	11.4	12.2	35
Carrots	5.9	7.9	8
Lettuce	1.1	2.6	14
Potatoes	11.0	13.6	24
Apple	1.5	3.3	3
Bananas	3.3	4.1	17

Source: Jones et al. (1992) Fleischwirtschaft International 2/2010 diet (e.g. vegans) and 15 g or more if meat only is consumed (e.g. the traditional diet of the Inuit) (Harris et al., 2002). Persons with a lacto-ovo-vegetarian diet were found to have a reduced creatine content in their muscles by comparison with omnivorous persons (Lukaszuk et al., 2002), indicating the significance of creatine supply via meat and fish.

Purchas et al. (2004) found 401 mg creatine per 100 g in fresh beef (*M. semitendinosus*). Lower concentrations were found in beef heart (298 mg/100 g) and in beef cheek (263 mg/100 g) and only minimal quantities in beef liver (16 mg/100 g). Comparable values (266 to 382 mg/100 g in beef muscle meat) were shown by later studies, which also pointed out that different production systems have no influence on the creatine concentration (Purchas and Busboom, 2005). They detected creatine quantities of between 278 and 511 mg/100 g in lamb, depending on the muscle analysed (Purchas et al., 2004) and levels between 247 and 374 mg/100 g are stated for pork (Mora et al., 2008). The creatine quantities in fish can lie between 200 and 1,000 mg/100 g, depending on the fish species, with the highest concentrations being found in herring (Balsom et al., 1994).

▶ Processing losses

Cooking largely influences the creatine content. After 90 min. at 70 °C, the creatine content in lamb drops from an average of 476 mg to 265 mg/100 g. Part of the loss is attributable to the conversion of creatine into creatinine under the influence of heat (Purchas et al., 2004). Studies by other scientists have also shown continuous reduction of creatine concentration over the duration of cooking (10 to 60 min.) (Harris et al., 1997). Furthermore, white coatings in the form of creatine efflorescence can occur on the surface of raw sausage matured over long periods, with higher pH values appearing to promote this (Kröckel, 2004).

Glutathione

The participation of glutathione (GSH) in the control and metabolism of cells was identified already in the 1950s and 1960s (Taylor et al., 1996). GSH is found in most plant and microorganism cells and in all mammal cells. It is a tripeptide (γ-L-glutamyl-L-cysteinylglycine; Fig. 7), that is formed by all cells (but mainly in the liver) from the three amino acids glutamic acid, cysteine and glycine (Lu, 1999; Wu et al., 2004).

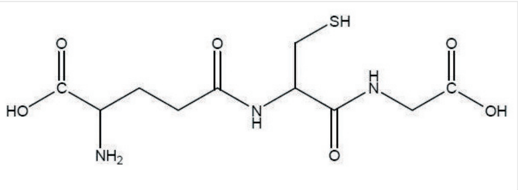
▶ Function

Glutathione is an extremely important intracellular antioxidant that also plays a role in detoxifying and eliminating carcinogens and toxins (Higdon and Hagen, 2006). It is also involved in the synthesis of tissue hormones, in the regulation of gene expression, DNA and protein synthesis, the immune system, cell growth and death, and in signal transmission. As many of these factors play key roles in illnesses (cancer, Alzheimer's, Parkinson's, AIDS, cardiac infarct, stroke etc.), glutathione also plays an important part here too (Wu et al. 2004, Townsend et al., 2003). Animal studies have shown that the glutathione levels in older animals are significantly lower than in younger animals, which is why the older are less able to respond to oxidative stress (Higdon and Hagen, 2006). A study on humans was also able to show a connection between the GSH level and the ageing process (Jones et al., 2002a).

Tab. 5: Lipoic acid content in commercially available meat (mg/100 g fresh weight)

	Liver	Kidneys	Heart	Muscle
Beef	0.06 – 0.11	0.09 – 0.13	0.07 – 0.10	0.02 – 0.04
Veal	0.03 – 0.05	0.05 – 0.07	0.05 – 0.07	0.01 – 0.02
Lamb	0.07 – 0.08	0.05 – 0.07	0.05 – 0.07	0.02 – 0.04
Pork	0.06 – 0.08	0.04 – 0.07	0.11 – 0.16	0.02 – 0.03

Source: Mattulat and Baltes (1992) Fleischwirtschaft International 2/2010



Source: Schmid Fleischwirtschaft International 2/2010

Fig. 7: Structure of glutathione

▶ Occurrence

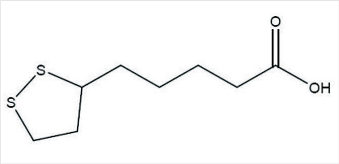
The GSH concentration in the cells is maintained stable. Losses are compensated by self-production and regeneration of GSH. The new synthesis depends on at least three factors: 1. the concentration of the first enzyme necessary for the synthesis, 2. the substrate availability (chiefly cysteine), and 3. the GSH concentration in the cell. GSH administered orally only reaches the cells to a very restricted extent if at all, as it is first dismantled into its amino acid constituents. However, these serve the cells as substrates for their own synthesis (Griffith, 1999). Dairy products, cereals and bread supply relatively low quantities of glutathione, while fruits and vegetables show medium to high concentrations, and fresh meat supplies relatively high quantities of glutathione (Tab. 4) (Jones et al., 1992). The glutathione content of a food only plays a secondary role for humans (as substrate supplier), however. The presence of sulphurous amino acids, chiefly cysteine (Tab. 4) is equally important. Generally, good nutritional state or above all adequate protein supply is extremely important for an optimal GSH level in the organism, and of course meat and meat products make a valuable contribution to this (Taylor et al., 1996; Wu et al., 2004).

Lipoic acid

Lipoic acid (LA), also known as thioctic acid, is in chemical terms 1.2-dithiolane-3-pentanoic acid (Fig. 8). It was originally discovered as a growth factor for bacteria in potato extract and subsequently isolated by Reed et al. (1951). LA is a natural substance that all animals and humans can synthesise themselves in small quantities. It may be present in two configurations (R and S; mirror image isomers), though in nature only (R)-LA occurs. The synthesis takes place from the short-chain fatty acid caprylic acid (C8) in the mitochondria, where LA acts protein-bound as coenzyme (Higdon and Hagen, 2006).

▶ Function

Lipoic acid is an essential cofactor for various enzyme complexes in the mitochondria that catalyse reactions in connection with the energy production and the breakdown of amino acids (Bustamante et al., 1998). Its task consists of transferring hydrogen and acyl groups. Moreover, LA together with its reduced form dihydrolipoic acid (DHLA) forms a biochemical redox system. This means that it acts as radical scavenger and antioxidant. DHLA can also regenerate other antioxidants present in the body, such as e.g. vitamins C and E, coenzyme Q_{10} or glutathione. However, this antioxidative effect has so far only been documented in the test tube (*in vitro*) and it is not yet clear whether the same effects are also displayed under physiological conditions (Smith et al., 2004; Jones et al., 2002b; Higdon and Hagen,



Source: Schmid
Fleischwirtschaft International 2/2010

Fig. 8: Structure of lipoic acid

2006). Moreover, both LA and DHLA can form complexes with free metal ions, such as e.g. iron and copper. These prevent oxidative damage, which is probably particularly important for avoiding neurodegenerative and other chronic diseases (Smith et al., 2004). Heavy metals can also be bound, which is why LA has a therapeutic potential in heavy metal poisoning (Smith et al., 2004). That is why LA has been admitted as a medicament for treating peripheral polyneuropathy in diabetics in Germany since 1966 (Higdon and Hagen, 2006; Smith et al., 2004).

▸ Occurrence

LA occurs naturally in foods too, where it is bonded to the amino acid lysine (Lipoyllysine). A large number of foods contain LA, but quantitative information about the content is rare. Animal tissues such as kidneys, liver and heart (Tab. 5) as well as some vegetable varieties such as spinach and broccoli are rich in lipoyllysine. Lower quantities are found e.g. in tomatoes, peas and cauliflower or in muscle meat (Mattulat and Baltes, 1992; Lodge et al., 1997). The absorption of LA from food does not lead to any measurable increase of the free LA in plasma and cells, however. On the other hand, highly dosed supplements in the form of free LA (50 mg or more) lead to a significant if only temporary increase in concentration (Hermann et al., 1996; Smith et al., 2004). These supplements are absorbed better by an empty stomach than together with food.

Bioactive peptides

Food protein is split by digestive enzymes in the gastro-intestinal tract of humans into peptides and amino acids. The same happens in fermentation processes, in meat maturing and in food processing. The peptides originating from foods can display various biological activities that are of interest for human health. So far, blood pressure-lowering, antimicrobial, antioxidative, antithrombotic, opioid, immune-modulating and other effects have been found (Zaloga and Siddiqui, 2004; Bauchart et al., 2006). The potential of milk and dairy products has been studied exhaustively in recent years, but little is known so far with regard to meat.

▸ Occurrence

Arihara et al. (2001), Fujita et al. (2000) and Katayama et al. (2007 and 2008) have isolated blood pressure-lowering peptides (inhibiting the Angiotensin I-Converting enzyme – ACE) from muscles of hens and pigs with various proteases. In this case it is not known whether these peptides also result naturally in the ripening or processing of meat. According to Arihara et al. (2001), an ACE-inhibiting activity was also shown in various commercially available fermented meat products, but it is uncertain whether this is actually caused by bioactive peptides. Bauchart et al. (2006) examined the occurrence of peptides with low molecular weight (<5 kDa) in fresh beef (*M. pectoralis profundus*) after 14 days of meat ripening and after additional cooking. The number of peptides was lowest in fresh muscle, increased during ripening, and was highest after cooking, though smaller peptides were broken down during ripening and cooking, which indicates altogether advancing peptidolysis. Carnosine, anserine and glutathione accounted for 89% of the peptides found in fresh muscle. The glutathione concentration declined in the course of meat ripening and all three showed losses due to cooking. Various further protein fractions were identified. However, it is not known whether they have any biological effect. There is generally still a great need for research with regard to bioactive peptides in the field of meat and meat products, and the coming years are sure to bring new findings.

Conclusion

A growing number of studies show that meat and meat products contain not only the customary vital nutrients but also additional, physiologically active components that can promote human health. Some of these substances are already being used in the form of highly dosed supplements, or their effect is being examined more closely. The quantities present in meat are much lower, however, but also develop their benefits. Enriching these substances naturally in meat or meat products would certainly be one possibility of generating functional foods of animal origin, or to stand out against competing products. However, further studies will be necessary in order to clarify the possibilities available in this respect.

References

Literature references can be downloaded at *www.fleischwirtschaft.com/literature* or requested from the author and the editorial office, respectively.

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