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Flavor formation in fermented sausages – The influence of bacteria

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SUMMARY

Flavor formation in fermented dried sausages is a complex process that has received a great deal of attention in the past years. Throughout the fermentation, drying and ripening periods the endogenous enzymes of the meat and fat act together with microorganisms and chemical reactions in creating a broad range of non-volatile and volatile components that make up the Đavor proÝle of the Ýnal product. This paper gives an up-dated insight into the more important Đavor compounds, their origin, precursors and formation. In particular the paper focuses on the bacterial inĐuence on Đavor formation and describes the latest results regarding amino acid degradation by meat cultures.

INTRODUCTION

In the Western world large amounts of fermented sausages are being consumed. In the EU alone the consumption was estimated to about 750.000 tons pr. year in 1995 corresponding to a value above 7 billion American dollars (L¸cke, 1998).

Fermented sausages are produced by fermenting, drying and ripening meat mince that has been stuffed into casings. The production procedure has been used for thousands of years and is considered being the oldest way of preserving meat. In traditional fermented sausages the fermentation is on-set by naturally occurring homo-fermentative lactic acid bacteria consuming the present or added sugars to lactic acid. Different species from the Micrococcaceae family (primarily **Staphylococcus** species) grow parallel to the lactic acid bacteria Đora and is responsible together with endogenous enzymes and chemical reaction for inducing the correct taste and aroma of the Ýnal product. In industrial sausage productions, in particular in Northern Europe, the processing procedure is shortened compared to the traditional methods in order to reduce expenses. This includes adding fast fermenting lactic acid bacterial starter cultures to the sausage mince, acidifying to low pH (<5.0) within 30-40 hours and ripening for a shorter time. The strong acidiÝcation compared to the traditional procedures inhibits or even kill the staphylococci, and therefore the Đavor development in the sausages is weaker even if relatively high amounts of starter staphylococci are added to the mince.

Keywords

Đavor, fermented sausage, bacteria, aroma compounds, taste compounds

In order to get hold of the old-fashioned flavor in fast fermented sausages, the flavor forming reactions have been extensively studied in the last 40 years. Mostly indirectly by investigating the degradation processes going on in the sausage lipids and proteins during production, but in the past years also by directly studying the profile of aroma compounds evolving during the process. Taste compounds have also been investigated, but not in great details and a lot of information is still lacking within this area.

Aroma compounds in fermented sausages

Over the years volatile compounds in the aroma fraction of fermented sausages have been collected and identified by several researchers. In January 2002 the total number of identified components had gone up to almost 400 (Stahnke, 2002). Those compounds have been summarized in Table 1 in their chemical classes, and this overview clearly shows that the range of volatiles in fermented sausages is very broad and the aroma profile therefore very complex. However, even if the total number of components is large, their quantity is very small. According to a study by Schmidt & Berger (1998) including both Northern and Mediterranean sausage types the total content of volatiles range from 70 to 180 mg/kg. Of this quantity, most authors state that terpenes and fatty acids dominate, followed by aliphatic alcohols, ketones, esters and sulfur compounds (Stahnke, 2002). Due to the enormous differences in sensory threshold values of volatile compounds this order changes when it comes to stating the relative sensory importance. In fact terpenes, originating from spices, do not contribute greatly to the total fermented sausage aroma even though present in the highest amounts. The most important compounds for the sausage aroma are methanethiol, eugenol (methoxy allyl phenol), straight chain short fatty acids (acetic, propanoic, butanoic, pentanoic and hexanoic acids), methyl-branched acids (2-methylpropanoic and 3-methylbutanoic acids), ketones (2-heptanone, 1-octene-3-one, diacetyl and 2,3-pentadione), straight-chain aldehydes (acetaldehyde, hexanal, octanal, 2,4-(**E**,**Z**)-decadienal and many more), methyl-branched aldehydes (2- and 3-methylbutanal, methional), several esters (in particular ethyl-2-methylpropanoate, ethyl-2- and 3-methylbutanoate and ethylbutanoate), sulfides (dimethylsulfide, dimethyltrisulfide), aromatics (2-phenylacetaldehyde, 2-phenylethanol, p-cresol and guiaicol) and other ring-closures such as 2-furfurylthiol and 2-acetyl-1-pyrroline (in molded sausages). If the sausages are added garlic different allylic sulfur compounds (in particular allyl-1-thiol and methylthiiran) are also of outmost importance (Meynier et al. 1999; Schmidt & Berger, 1998; Stahnke, 1994, 1995, 1998, 2000; Stahnke et al., 1999).

Table 1. Volatile compounds identified in fermented sausages*

Compound class	Compound	Identified number of compounds
Hydrocarbons	Saturated	16
	Unsaturated	7
Aldehydes	Saturated	17
	Unsaturated	17
	Branched	7
Ketones	Saturated	15
	Unsaturated	2
	Branched	9
	Di-ketones	3
	Hydroxy-ketones	3
	Cyclic	9
Alcohols	Saturated	16
	Unsaturated	9
	Branched	17
	Di-ols	3
	Cyclic	1
Acids	Saturated	12
	Unsaturated	4
	Branched	6
	Di-acids	2
	Hydroxy-acids	1
Esters	Methyl esters	12
	Ethyl esters	20
	Branched alcohol esters	7
	Other	6
Sulfur comp.	Thiols	4
	Sulfides	21
	Thiophenes	2
	Other	1
Aromatic comp.		48
O-heterocycles		26
Terpenes		42
Nitrogen comp.		34

* Modified from Stahnke (2002).

Sensory profiling studies have given some indications to how sausage flavor descriptors are related to the various aroma compounds. Buttery odor seems to correlate with diacetyl, cured/mature odor with methyl ketones, 2-methylpropanal, 2- and 3-methylbutanal and ethyl esters, some allylic compounds with garlic flavor, smoked flavor with aromatic and O-heterocyclic compounds, acid flavor with short straight-chain acids (acetic, butanoic and hexanoic acid), rancid flavor with hexanal, octanal,

nonanal and decanal, and cheesy odor with butanoic, 2-and 3-methylbutanoic and 2-methylpropanoic acids (BerdaguÈ et al., 1993; Hagen et al., 1996; Stahnke, 1994, 1995; Stahnke et al., 1999; Viallon et al., 1996). However, a precise relationship between various sausage types and the volatile components is still lacking even though some information do exist on speciÝc odor compounds. Figure 1 shows a plot from a principal component analysis on data from a gas chromatography olfactometry study on ten different European sausages. Aroma fractions from the sausages were separated in a gas chromatograph and the efÐuent sniffed by a 5-member panel in triplicates, revealing 81 different odors detected at least three times. The plot shows that some odors were present in all sausage types (lying close to origo) whereas others were speciÝc to one or a few sausages. Mediterranean sausages with mold on the surface were clearly differentiated from the Northern European smoked sausages by being placed, respectively, in the upper and lower part of the plot. The Spanish sausage was an outlier in this respect since it was neither smoked, nor covered with mold, but was relatively sour. The odor notes that separated the sausages from each other were garlic, onion and fruity-like notes on the Ýrst axis since none of the Belgium sausages were added garlic and the fruity notes were more dominating in the sausages on the right. The main garlic odor arose from allylmethylsulÝde, salami/onion odor from allyl-1-thiol and the fruity/candy-like notes from different ethyl esters. The Northern smoked sausages were in particular separated from the Mediterranean sausages due to the popcorn note on the very top and the coffee note at the very bottom. The coffee note was identiÝed as 2-furfurylthiol, a compound, which presumably arises from smoke or reactions between smoke components and sulfur-containing amino acids in the meat surface. The popcorn note was identiÝed as 2-acetyl-1-pyrroline. The components close to origo that were common to all sausage types and therefore, presumably, were responsible for a basic dried sausage odor were primarily methanethiol, methional, dimethylsulÝde, dimethyltrisulÝde, diacetyl, ethylbutanoate, ethyl-2-methylpropanoate, acetaldehyde, acetic acid, butanoic acid, 2-methyl-propanoic acid, 3-methylbutanoic acid, guiaicol, hexanal, octanal, 1-octene-3-one and a few more that were not possible to identify (Stahnke, 2000). However, if a combination of those compounds actually produce a dried sausage Ðavor still needs to be veriÝed.

Taste compounds in fermented sausages

The non-volatile substances in sausages that may impart sausage taste and Ðavor are numerous, but they have not been much studied. However, due to the molecular speciÝcations of the taste receptor sites compounds with a molecular weight less than 6000 amu could be of relevance. This includes salts, organic acids, sugars, nucleotides, free amino acids and smaller peptides (Stahnke, 2002). Of those components NaCl, lactic and acetic acids and perhaps also propanoic acid are the primary contributors to salty and acidic taste sensations. However, studies have indicated that acids such as citric and formic acids are present in concentrations that could inÐuence sour taste as well (Bruna et al., 2000, 2001). If large amounts of residual sugar are present in the Ýnal product, sugar may also have an inÐuence on taste; perhaps by being a taste enhancer rather than triggering sweet taste. The sensory threshold value of sucrose in water is approx. 0.6 w% and this concentration is often exceeded in residual sugars (Plattig, 1984; Stahnke, 2002). The nucleotides inosine monophosphate, inosine and hypoxanthine are still present in fermented sausages after ripening, but it was concluded by Mateo et al. (1996) that their amount was below the sensory threshold value.

Free amino acids and smaller peptides contribute to Ðavor of sausages by imparting a sort of bouillon or umami note to the Ðavor, but they could also trigger the sweet, sour or bitter taste receptors. Mateo et al. (1996) calculated that leucine and valine were present in levels that would produce a bitter sensation, glutamic acid an umami response, alanine a sweet response, and valine and lysine both sweet and bitter responses. This was partly conÝrmed by Henriksen & Stahnke (1997) who showed that bitterness correlated to lysine, valine, leucine, proline and isoleucine, and that bouillon (umami) taste correlated to a mixture of different amino acids and peptides.

The total amount of free amino acids in sausages is in the range of 5-24 g/kg dry matter depending on sausage type and ripening time, but it is not yet known how much the actual amount of free amino acids and peptides affect Ðavor. In some cases higher concentrations of peptides and amino acids correlate with better taste, in other cases the opposite (Zapelena et al., 1997, 1999; Diaz et al., 1996, 1997).

Formation of taste and aroma compounds

Amino acids and peptides

During ripening proteins in the sausage matrix are partially hydrolyzed by proteolytic enzymes into smaller proteins and peptides (Johansson et al., 1994; Astiasaran et al., 1990). Both the myoÝbrillar and sarcoplasmic protein fractions are affected (Diaz et al., 1996, 1997).The peptides are further hydrolyzed into free amino acids and this process goes on more or less throughout the ripening period (Waade & Stahnke, 1997). The degradation of large proteins into smaller proteins, peptides and amino acids is caused both by proteolytic and peptidolytic activities of the microbial and endogenous enzymes. But there is some discussion as to which mechanisms are the dominating. Presently, it is assumed that degradation of proteins into peptides is caused by the tissue enzymes, primarily, and the further degradation into amino acids by microbial peptidases (Molly et al., 1997). However, it has been shown that several of the sarcoplasmic and myoÝbrillar proteins

in pork slices are degraded by species of **Staphylococcus**, **Penicillium** and **Debaryomyces** (Martìn et al., 2001) and that several peptidases do exist in muscle tissue (Toldra et al., 1993, 2000). Additionally, it has been shown that most **Staphylococcus** and **Kocuria** species isolated from sausages are proteolytic against gelatin and casein (Coppola et al., 1997; Garcìa-Varona et al., 2000), that several **Lactobacillus** strains hydrolyze sarcoplasmic proteins (Fadda et al., 1998) and that all strains of **Pediococcus pentosaceus** isolated from a Greek cheese exhibited proteinase activity as well as endopeptidase, dipeptidase, aminopeptidase and carboxypeptidase activity (Vafopoulou-Mastrojiannaki et al., 1994).

The formation of very small peptides and amino acids is of outmost importance for the flavor development of fermented sausages, since those components act directly as taste compounds and, perhaps even more important, are important pre-cursors for the formation of aroma compounds arising from amino acid catabolism as described further below.

Lactic acid

Lactic acid is primarily produced by the lactic acid bacteria added to the mince or by the naturally occurring flora already present on the meat. Depending on the amount and kind of sugars available, fermentation temperature, water activity, sausage diameter, buffering capacity etc. the lactic acid production is accompanied by a parallel pH-fall that may last for more than a week (L¸cke, 1998). Lactic acid measured in various European fermented sausages was in the range of 4-31 g/kg dry matter (Stahnke, 2002).

The lactic acid bacteria used as starter cultures for fermented sausage production are either homo-fermentative **Lactobacillus** or **Pediococcus** species that produce D- or L-lactate or a mixture of both. The most common starter cultures are **L. plantarum, L. sakei, L. pentosus, P. pentosaceus** and **P. acidilactici** whereas in traditionally fermented sausages the predominant lactic acid bacteria are **L. sakei**, **L. curvatus** and **L. plantarum** (L¸cke, 1998).

Short straight-chain acids

Acetic, propanoic and butanoic acids are derived from microbial degradation of pyruvate which has many origins such as glycolysis, amino acid fermentation and other catabolic and anabolic pathways (Genomenet 2003). As outlined above, those acids both have taste and aroma properties. Lactic acid bacteria as well as **Staphylococcus** species have been shown to produce the short straight-chain volatile acids (Gottschalk, 1986; Soendergaard and Stahnke, 2002).

There are great variations in the reported amounts of volatile acids in fermented sausages, but acetic acid lies in the range of 0.2-2.5 g/kg dry matter in different European sausages and butanoic acid in the range of 0.9-29 mg/kg dry matter (Stahnke, 2002). It has been shown that sausages are added glucose and lactic acid bacteria and which are fermented at high temperature contain higher levels of straight-chain acids, i.e. this is expected to be the case for North European sausages (Schmidt & Berger, 1998; Stahnke, 1995).

Straight-chain aldehydes

The flavor important straight-chain aldehydes such as hexanal, octanal, decanal and 2,4-decadienal are formed during fatty acid autoxidation of the unsaturated fatty acids and is in general steadily increasing in concentration during sausage ripening. Hexanal primarily arises from linoleic and arachidonic acids and decanal from oleic acid. The very potent unsaturated 2,4-decadienals arise from linoleic acid and arachidonic acid (Grosch, 1982).

Hexanal is the aldehyde present in highest amounts ñ the level is between 0.01-109 mg/kg for different sausage types and is a typical compound to look for if investigating rancidity (Stahnke, 2002; Tjener et al., 2003). Free fatty acids are said to be more prone to oxidation than when bound in the triglyceride molecule. But even so, extensive lipolysis during the maturation time has not been shown to produce sausages with higher oxidation level or with more rancid flavor (Nagy et al., 1989; Zalacain et al., 1997).

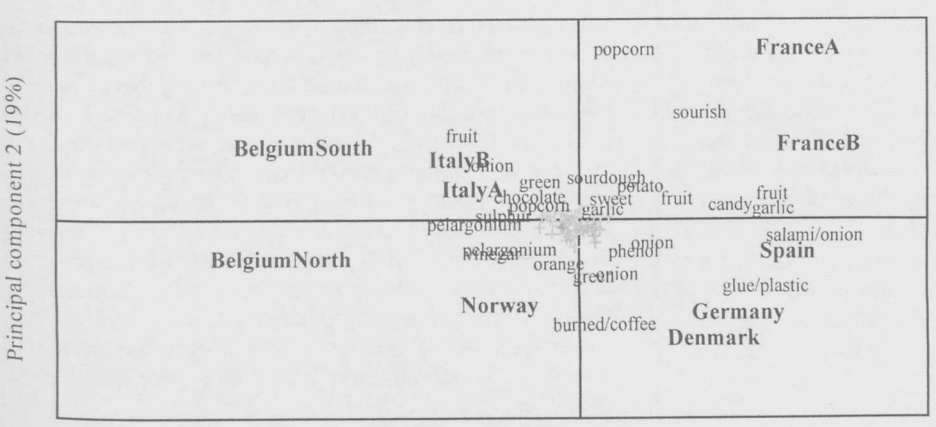

Figure 1. Combined scores and loadings plot from a principal component analysis on 81 odours detected by gas chromatography olfactometry on ten dried sausages from different countries. Odour notes in the centre of the plot have not been speciÝed due to lack of space (Stahnke, 2000).

Microbial growth in the sausage mince can both increase and decrease the level of aldehydes. Lactic acid bacteria and certain **Kocuria** species produce hydrogen peroxide (Alford et al., 1971; L¸cke, 1998; Smith & Alford, 1969) which may oxidize fatty acids and enhance the production of 2-alkenals and 2,4-alkadienals (Alford et al., 1971). On the other hand, several strains of **Staphylococcus** are said to reduce the level of oxidation by consuming the oxygen diffusing into the sausage, by producing enzymes with antioxidant properties such as catalase or superoxide dismutase, or by converting the aldehydes into other compounds (BarriËre et al., 2001; Stahnke, 1994; Talon et al., 1999, 2000; Vergnais et al., 1998).

Methyl-branched aldehydes and acids

The methyl-branched aldehydes, 2- and 3-methylbutanal, 2-methylpropanal, and the corresponding acids 2- and 3-methylbutanoic and 2-methylpropanoic acids are degradation products of the amino acids isoleucine, leucine and valine, respectively, but other pathways of formation through pyruvate also exist for those compounds (Beck et al., 2002). The microbial formation of the methyl-branched compounds has been extensively studied in the past years since they are of outmost importance for the Ðavor of fermented sausages together with catabolic products of phenylalanine and methionine. Also, they participate in secondary reactions together with ethanol producing highly Ðavor active ethyl esters (see below).

In general, the concentration of methyl-branched aldehydes increases during ripening to a certain point, after which it decreases, probably due to conversion into the corresponding acids (Cantoni et al. 1967; Mateo & Zumalac·rregui 1996; Sunesen et al., 2001; Tjener et al., 2003). However, there are also reports on a continuous increase (Croizet et al., 1992; Olesen et al., 2003). The concentration of methyl-branched aldehydes and acids is in the range of 0.02-0.07 mg/kg and 0.3-8 mg/kg dry matter, respectively for different sausage types (Schmidt & Berger, 1998; Tjener et al., 2003). Fast fermented sausages seem to contain higher amounts of the acids (Schmidt & Berger, 1998; Stahnke, 1995; Tjener et al., 2003) and less amounts of the aldehydes (Stahnke, 1995; Tjener et al., 2003), which could be one major cause for the Ðavor differences between traditional and fast fermented products.

It is most likely that the methyl-branched aldehydes and acids are formed by microorganisms in the mince, in particular by **Staphylococcus** and **Kocuria** species, though chemical Strecker degradation produces the same compounds (Larrouture et al., 2000; Masson et al., 1999; Montel et al., 1996; Soendergaard & Stahnke, 2002; Stahnke, 1999a; Vergnais et al., 1998). The pathways of formation are not Ýnally solved but it has been shown that the Ýrst step is a transamination reaction catalyzed by the branched chain amino acid aminotransferase (ilvE) converting the amino acid into an α-keto acid which is further degraded into the corresponding aldehyde, acid and other components by various decarboxylation and dehydrogenase steps. The rate limiting step in the conversion of the α-keto acid to the methyl branched acid is the conversion of the α-keto acid to the aldehyde (Beck et al., 2002). The gene for ilvE (**ilvE**) in **S. carnosus** S1 (Wisby) has been identiÝed and sequenced and a deletion mutant has been constructed. Investigations with the deletion mutant showed that ilvE is an essential enzyme in the catabolism of isoleucine and valine and is very important in the catabolism of leucine (Madsen et al., 2002). Also, it has been shown that catabolites from isoleucine are essential for **Staphylococcus** growth, since they are converted into anteiso-fatty acids that are incorporated into the cell membrane. Catabolites from leucine and valine are incorporated as iso-fatty acids, but in **S. xylosus** and **S. carnosus** the dominating fatty acids in the cell membrane are anteiso-fatty acids (60-85%) (Kaneda, 1991; Madsen et al., 2002). This substantiates earlier studies indicating an inverse relationship between growth and formation of the methyl-branched compounds from amino acid degradation (Stahnke, 1999b).

In general, **S. carnosus** strains seem to produce higher amounts of methyl-branched compounds compared to **S. xylosus, S. warneri, S. saprophyticus, S. equorum** and **Kocuria** (Larrouture et al., 2000; Montel et al., 1996; Olesen et al., 2003; Soendergaard & Stahnke, 2002; Stahnke, 1999a; Stahnke et al., 2002). However, this could simply be due to the higher salt tolerance of **S. carnosus** that enables the bacterium to grow/survive better in the sausage mince. Nitrate addition increases formation of methyl-branched acids in mince and sausages (Olesen et al., 2003; Stahnke, 1999b). This could as well be due to better growth of the **Staphylococcus** strains since **Staphylococcus** species are able to exploit nitrate as an electron acceptor during respiration in the oxygen poor environment of the sausage.

Ketones

Diacetyl is one of the very potent aroma compounds in fermented sausages. It has a very low sensory threshold value and is present in 0.008-0.3 mg/kg dry matter in different sausage types (Schmidt & Berger, 1998; Tjener et al., 2003). Diacetyl is formed from pyruvate; probably both by lactic acid bacteria and Micrococcaceae species (Montel et al., 1996; Stahnke, 1999a). In particular **S. xylosus** strains seem to produce much higher amounts than **S. carnosus** strains (Soendergaard & Stahnke, 2002). Both in sausages and in meat mince the amount of diacetyl and 2-butanone increases with acidiÝcation speed (Stahnke, 1995, 1999; Tjener et al., 2003), but over time diacetyl is converted into acetoin, 2,3-butandiol and 2-butanone (Margalith, 1985; Olesen et al., 2003).

Methyl ketones such as 2-pentanone, 2-heptanone and 2-nonanone are formed by decarboxylation of free fl-keto acids or by incomplete fl-oxidation of free fatty acids (Okumura & Kinsella, 1985). In general, the methyl ketones contain one carbon atom less than the precursor acid, but it has been shown that **S. carnosus** produces the acyl-CoA intermediates of C8,C10,C12 and C14 from

palmitoyl-CoA during respiration (Engelvin et al., 2000). The majority of fungi from the **Penicillium** genus produce methyl ketones, germinating spores as well as the mycelium and in mold-fermented sausages methyl ketones may arise from fungal growth as well as bacteria. The amount of methyl ketones (Croizet et al., 1992; Sunesen et al., 2001) increases steadily during ripening and has been shown to reach a concentration of 0.04-0.09 mg/kg dry matter for 2-heptanone and 0.05-0.16 mg/kg dry matter for 2-nonanone in various sausage types (Schmidt & Berger, 1998).

Esters

Esters are formed during secondary reactions involving alcohols and acids and often they appear late in the ripening period (Croizet et al., 1992; Mateo & Zumalac·rregui, 1996). According to Schmidt & Berger (1998) the total amount of esters in different commercial products was in the range of 0.2-0.6 mg/kg dry matter.

The amount of an ester often correlates with the amount of the pre-cursor alcohol (Soendergaard & Stahnke, 2002; Stahnke, 1994, 1995) or acid (Stahnke, 1995; Montel et al., 1996) depending on the type of ester. Esters are probably formed by microbial esterases but perhaps also by spontaneous reactions. Lactic acid bacteria, **Staphylococcus**, yeast and mold form esters (Montel et al., 1996; Olesen & Stahnke, 2000; Stahnke, 1999a). It has been shown that esterases from **S. warneri** and **S. xylosus** produce ethyl esters from several straight-chain acids with carbon number higher than C5, and for some acids, also with alcohols longer than ethanol (Talon et al., 1996a). Additionally, it has been shown that several strains of **Staphylococcus** form short ethyl esters from the acetic, butanoic, pentanoic, hexanoic, decanoic, 2-methylbutanoic and 3-methylbutanoic acids (Talon et al., 1996b, 1998).

Sulfur compounds

Methional, methanethiol, dimethyldisulÝde and dimethyltrisulÝde could all arise from microbial degradation of methionine. Their formation has not been studied in **Staphylococcus**, but the pathway is probably similar to what goes on in **Lactococcus**: Methional is formed during transaminase and decarboxylase reactions of methionine, methanethiol by elimination of the side chain of methionine by a lyase and also by degradation of methional or its precursor keto-acid. Methanethiol oxidizes to give dimethyldisulÝde and dimethyltrisulÝde (Yvon & Rijnen, 2001).

Many lactic acid bacteria, yeast and **Staphylococcus** species are capable of forming the sulfur compounds, but their efÝciency is highly strain dependent (Olesen & Stahnke, 2000; Stahnke, 1999a; Soendergaard & Stahnke, 2002; Yvon & Rijnen, 2001). Aerobic conditions seem to promote the formation of dimethyldisulÝde and dimethyltrisulÝde (Stahnke, 1999b).

Aromatic compounds

Several aromatic compounds such as 2-phenylethanol, phenylacetaldehyde, p-cresol, guiaicol and perhaps also benzaldehyde are believed to affect sausage Đavor (Schmidt & Berger, 1998; Stahnke, 1994, 1995; Stahnke et al., 1999). Some originate from microbial metabolism of phenylalanine (Genomenet, 2002; Montel et al., 1996; Stahnke, 1999; Yvon & Rijnen, 2001), but others, such as the phenols, also from smoke components (TÛth & Potthast, 1984). Tjener et al. (2003) detected phenylacetaldehyde and 2-phenylethanol in concentrations of 0.13 mg/kg and benzaldehyde in levels of 0.02 mg/kg in traditional Danish sausages.

Both **S. xylosus** and **S. carnosus** seem capable of forming phenol and benzaldehyde during growth in sausage minces (Soendergaard & Stahnke, 2002; Stahnke, 1999a), but their pathway of formation has not been studied in **Staphylococcus.** In **Lactococcus** phenylacetaldehyde arises from transamination of phenylalanine into phenylpyruvate followed by decarboxylation, 2-phenylethanol by reduction of the aldehyde. Benzaldehyde is formed by oxidation of phenylpyruvate. p-Cresol is produced from tyrosine via transamination and a number of more steps (Yvon & Rijnen, 2001) and has been detected in levels of 0.06-0.1 mg/kg dry sausage matter (Schmidt & Berger).

Nitrogen compounds

The very potent popcorn-odorous 2-acetyl-1-pyrroline (2A1P) has been detected in mold-fermented sausages and is very typical for the aroma of Mediterranean sausage types as described above. 2A1P is particular found in the sausage edge; 0.2-0.7 mg/kg in French sausages (Stahnke, 2000) and is probably formed by the molds growing on the sausage surface or through a synergy between the molds and the bacteria. Degradation of either ornithine, glutamate and/or proline seems to be the most likely origin (Romanczyk et al., 1995).

CONCLUSIONS

Flavor formation in fermented sausages is a very complex process. Research within the last ten years has given a lot of detailed knowledge on the sort of compounds being of major importance to the Đavor. Also, the basic enzymatic and microbial reactions leading to those compounds have been more enlightened. However, the link between the various volatile compounds and the perceived aroma and Đavor still needs some attention in order to fully understand and control the Đavor forming reactions during sausage processing.

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