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Gas chromatography-olfactometry analysis of beef meat originating from differently fed Belgian Blue, Limousin and Aberdeen Angus bulls

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Abstract

The volatile compounds of cooked meats from differently fed Belgian Blue, Limousin and Aberdeen Angus bulls were isolated in a model mouth apparatus. Their odour activity was determined by gas chromatography-olfactometry based on a detection frequency method. A total of thirty compounds possessed an odour activity in cooked beef meat. Significant influences of breed and diet on the development of the odour-active compounds of cooked beef meat were observed. The meat of Belgian Blue seemed to generate more odour-active compounds and to be more influenced by the feeding diet than the other breeds. This could be the consequence, at least in part, of its double-muscle condition. However, no obvious justifications could be given to explain the influence of the diet. Different chemical compositions are factors of importance for explaining the different aroma profiles between breeds, but some other parameters should also play an important role.

Keywords: GC-O; Model mouth; Cooked beef; Odour active compound; Breed; Diet

1. Introduction

Isolation of flavour compounds from foodstuffs has always been a challenge. It has to reflect the concentration and the ratios of the different flavour compounds when present in the mouth and in the nose. Distillation/extraction (Gasser & Grosch, 1988; Guillard, Le Quere, & Vendeuvre, 1997), static headspace (Guth & Grosch, 1994), purge and trap (Carrapiso, Ventanas, & Garcia, 2002; Elmore, Mottram, Enser, & Wood, 2000), and solid-phase microextraction (Machiels & Istasse, 2002; Ruiz, Cava, Ventanas, & Jensen, 1998) are the main methods for the isolation of volatile compounds in meats. However, mastication and saliva are factors of importance that have to be taken into account when considering the aroma release of flavour compounds from foods during consumption (van Ruth & Roozen, 2000). van Ruth, Roozen, and Cozijnsen (1994) proposed a model mouth for the isolation of volatile compounds from foods. The volatile compounds isolated in the model mouth showed great similarity to those released in the human mouth. More recently, Machiels, van Ruth, Posthumus, and Istasse (2003) isolated volatile compounds from cooked Irish beef meats with an artificial mouth. Gas chromatography (GC)-olfactometry (O) is an efficient tool for the analysis of key odorants in food (Acree, 1993; Grosch, 1993; Marsili & Miller, 2000; van Ruth & Roozen, 1994; van Ruth et al., 1994). Several olfactometry techniques are available to determine the potency of the flavour compounds (van Ruth, 2001). Amongst those, detection frequency records detected odours over a group of assessors. The number of assessors detecting an odour is correlated to the odour intensity (van Ruth & O'Connor, 2001). Detection frequency combines an easy use and a relatively fast time of analysis.

Maillard reaction between amino acids and sugars and lipid thermal degradation are the main sources of volatile compounds in cooked meat. The overall odour

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profile of cooked meat depends on the species (Gasser & Grosch, 1988), the breed (Monin, 1991), the animal's diet (Maruri & Larick, 1992), the cooking method (Wasserman, 1979) and some other parameters, such as meat processing (Machiels et al., 2000). Among these, breed and diet are factors of importance as they induce different chemical compositions of the meat, especially fat content and fatty acid composition. Although the volatile composition of cooked beef meat has been extensively investigated (Kerscher & Grosch, 1997; Specht & Baltes, 1994), few studies have focussed on the determination of the key odorants of cooked beef meat originating from animals differently fed or of different breed. Furthermore, a model mouth apparatus to isolate the volatile compounds could contribute to a better understanding of the aroma profile of cooked meat as really perceived retro-nasally in the human mouth.

The aim of the study was to investigate the aroma profile of cooked beef meat originating from animals of three different breeds and fed two fattening diets. In this paper, the model mouth apparatus, a dynamic tool for volatiles extraction, was used to isolate the volatile compounds of cooked beef meat. Their odour activity was assessed by GC-O and their identification was performed by GC-mass spectrometry (MS) and confirmed by retention indices calculations.

2. Materials and methods

2.1. Materials

Belgian Blue (BB), Limousin (Lim) and Aberdeen Angus (AA) bulls were offered two different fattening diets, based either on cereals-rolled barley and crushed maize (cereal based) – or on dry sugar beet pulp (pulp based) and supplemented with soja bean meal and linseed meal as protein source (Table 1). Each breed/diet combination included six bulls. Animals were slaughtered at a commercial abattoir at the age of 18 months.

Table 1
Ingredient composition of pulp-based and cereal-based diets of Belgian Blue, Limousin and Aberdeen Angus bulls

Ingredient composition (% w/w)	Dietary treatment	
	Pulp-based	Cereal-based
Spelt	10	10
Barley	10	25
Maize	10	25
Dry sugar beet pulp	50	18.3
Soja bean meal	8	8
Linseed meal	8	8
Mollasses	3	3
Mineral mixture	1	1
Chalk	0	0.5
Bicarbonate	0	1.2

Muscles (*longissimus thoracis*) from BB, Lim and AA bulls were trimmed of subcutaneous fat, vacuum-packed and stored at −18 °C. Chemical composition analyses have been performed on the meat. It appeared that meat composition was homogeneous within each group. One sample per group was randomly selected for sensory analyses.

2.2. Isolation of volatile compounds

Between 10 and 15 g of frozen meat were hand-cut and allowed to stand at room temperature for 30 min in a 100 ml Duran auto-clavable bottle fitted with air-tight polytetrafluoroethylene (PTFE)-lined screw top (Fisher Ltd., Loughborough, UK). The meat was cooked at 150 °C in an oil bath for 25 min, cooled and stored at 4 °C overnight. Cooked meat (5 g) was warmed up at 37 °C for 15 min and then transferred into the model mouth apparatus with 2 ml of artificial saliva. The headspace of the meat was flushed with purified nitrogen (100 ml/min) and the volatile compounds were trapped on Tenax TA (SGE, Kiln Farm Milton Keynes, UK) while a plunger was making up and down screwing movements to simulate mastication. Desorption of the volatile compounds from Tenax was performed on a thermal desorption device (SGE concentrator/headspace analysis injector, Kiln Farm Milton Keynes, UK). GC was carried out on a Varian 3400 CX Gas Chromatograph. GC-O conditions were the same as described previously (Machiels et al., 2003). A series of *n*-alkanes was injected under the same conditions in order to calculate retention indices.

2.3. Gas chromatography-olfactometry analysis

Twelve assessors were selected (ten females, two males, aged 19–35) for GC-O analysis. After GC-O training sessions, odour descriptors were selected by the sniffing panel and clustered after group sessions. The descriptors used for the sample analyses were: sulphury, chocolate, caramel, fruity, burnt, sweaty, earthy, fermented, green, fresh, chemical, oily, buttery, onion, nutty and meaty. One of these descriptors had to be chosen for each compound detected by the assessors at the sniff port. Tenax tubes without adsorbed volatile compounds were used as dummy samples to determine the signal to noise level of the group of assessors. Two replicates were performed for each type of meat.

2.4. Gas chromatography-mass spectrometry analysis

The volatile flavour compounds were identified by a combined GC (Varian Star 3400 CX, JVA Analytical Ltd., Dublin, Ireland) and MS (Varian Saturn 3, JVA

Analytical Ltd.) fitted with a thermal desorption device (Tekmar Purge and Trap 3000 concentrator, JVA Analytical Ltd.). Mass spectra were obtained with a 70 eV electron impact ionisation, while the mass spectrometer was scanning masses from m/z 40 to 400 at a speed of 3 scans/s. The column and oven temperature programmes were similar to those used for the GC-O analyses. The volatile flavour compounds were first identified by comparing their mass spectra with those of NIST/EPA/NIH Mass Spectral Database and with those of pure compounds. Wherever possible, identities were confirmed by comparing their retention indices and odour characteristics with either those of published values (Kondjoyan & Berdagué, 1996) or standards.

2.5. Statistical analysis

A two-way analysis of variance (SAS procedure) was carried out on the detection frequency data for each odour-active compound in order to determine the overall effect exerted by diet and breed. To compare detection frequency scores, we also evaluated least square significant differences between samples (Pollien et al., 1997). A detection frequency variation of two panellists has been considered as a significantly different score (95% confidence).

3. Results and discussion

3.1. General

The volatile compounds of differently fed BB, Lim and AA cooked meat were isolated in a model mouth apparatus. They were subjected to GC-O, based on the detection frequency method, to determine the odour-active compounds out of the range of volatiles. The odour-active compounds were identified by GC-MS and further characterised by their retention indices and odour properties. The effect of breed and diet on the aroma profile of cooked beef meat was also studied.

3.2. Aroma composition of beef meat

A total of thirty volatile compounds possessed an odour activity in the aroma of cooked beef meat, i.e. they were detected by more than one assessor (Table 2). The injection of a dummy sample showed that a frequency above one detection could be considered as a signal while one detection belongs to the noise level.

Sixteen compounds were derived from Maillard and Strecker reactions, seven from lipid degradation and seven compounds were not identified. Compounds from lipid oxidation included saturated and unsaturated aldehydes and ketones. Volatile compounds from Maillard reactions included sulfur- and nitrogen-containing compounds, Strecker rearrangement products, two thiazoles and 2,3-diethyl-5-methylpyrazine.

Seventeen compounds have already been described as odour-active compounds in cooked beef meat: 2,3-butanedione (sweet, buttery), 2- and 3-methylbutanal (pungent, green, sweet, roasty), 2,3-pentanedione (buttery, lemon, sweet, fruity), dimethyl disulfide (mouldy, pungent, rubbery, onion), hexanal (green), heptanal (green, fatty, oily), methional (cooked potato), dimethyl trisulfide (cabbage, sulfurous), 2-octanone (fruity, musty), octanal (fruity, green), 2-acetylthiazole (roasty), 2-octenal (fruity, fatty, tallowy), 2-nonenal (tallowy, fatty), 2,3-diethyl-5-methylpyrazine (earthy, roasty, meaty), 2,4-nonadienal (fatty) and benzothiazole (pyridine-like, metallic) (Cerny & Grosch, 1992; Gasser & Grosch, 1988; Guth & Grosch, 1994; Specht & Baltes, 1994). Ethyl acetate (caramel, sweet) and 2-butanone (chemical, burnt) have been shown to contribute to the aroma of commercial cooked Irish beef meat when the volatile compounds were isolated under mouth conditions (Machiels et al., in press). Hydrogen sulfide (rotten eggs, sewage), methanethiol (rotten eggs, meat, cheesy) and 2-methylpropanal (toasted, fruity, pungent) have been found to participate to the aroma of Iberian Ham (Carrapiso et al., 2002); however, their odour activity is reported for the first time in cooked beef meat. Carbon disulfide is also reported for the first time as an odour-active compound in cooked beef meat. It has been identified in the aroma profile of dry sausage (Berdagué, Monteuil, Montel, & Talon, 1993). The remaining seven compounds were not identified. The MS signal was too weak or not clear enough to be analysed, the retention indices and the odour characteristics did not match any known flavour compounds. The low odour threshold of several odorants could explain that, despite low concentration and correlated absence of signal in the chromatograms, an odour was perceived anyway at the sniff ports.

A two-way analysis of variance, with breed and diet as variables, was carried out on the detection frequency data for each odour-active compound. Twenty-one compounds were significantly ($p < 0.05$) affected by either diet or breed. However, no significantly different detection frequency scores were observed for five of the most intense peaks: hydrogen sulfide (sulfury, sweaty, chemical), carbon disulfide (sulfury, fruity, burnt), 2,3-butanedione (caramel, buttery), 3-methylbutanal (chocolate, caramel, green, nutty) and hexanal (green, fruity). The latter was derived from the autoxidation of both oleic and linoleic acid (Elmore, Mottram, Enser, & Wood, 1999). The other compounds are derived from Maillard reactions. Hydrogen sulfide and carbon disulfide are degradation products of sulfur-containing amino acids such as cysteine while 2,3-butanedione originates from the thermal degradation of sugars.

Table 2
Volatile flavour compounds of Belgian Blue (BB), Limousin (Lim) and Aberdeen Angus (AA) bulls fed two different diets, determined by gas chromatography-olfactometry analysis, the compounds' retention indices (RI), detection frequencies (12 assessors, average of two sessions), statistical significance of breed and diet (P_{breed} and P_{diet}), odour descriptors, and method of identification

No.	RI[a]	Compound	Detection frequency						P_{breed}[b]	P_{diet}	Odour descriptors	Method of identification[c]
			BB		Lim		AA					
			Pulp	Cereal	Pulp	Cereal	Pulp	Cereal				
1	<500[d]	Unknown	2	2	2	3	9	8	*	NS	Chemical, fruity, fresh	
2	<500	Hydrogen sulfide	9	8	11	8	9	9	NS	NS	Sulfury, sweaty, chemical	ms
3	<500	Methanethiol	9	4	5	2	–	–	**	*	Sulfury, sweaty	ms
4	549	Carbon disulfide	6	8	7	6	6	5	NS	NS	Sulfury, fruity, burnt	ms + ri
5	582	2-Methylpropanal	–	–	6	8	7	6	***	NS	Burnt, nutty, oily	ms + ri
6	595	2,3-Butanedione	7	9	9	9	9	10	NS	NS	Caramel, buttery	MS + RI
7	606	2-Butanone	5	2	–	–	–	–	***	**	Chocolate, buttery	MS + RI
8	621	Ethyl acetate	8	4	–	–	–	–	***	***	Chemical	ms + ri
9	633	Unknown	3	–	–	–	–	–	**	*	Fruity	
10	656	Unknown	4	2	–	–	–	–	**	**	Meaty, fruity, chocolate	
11	665	3-Methylbutanal	8	8	9	7	12	10	NS	NS	Chocolate, caramel, green, nutty	ms + ri
12	675	2-Methylbutanal	4	6	6	2	3	–	*	NS	Nutty, burnt, onion	ms + ri
13	715	2,3-Pentanedione	6	9	5	6	7	6	*	NS	Caramel, buttery, fruity	MS + RI
14	750	Dimethyl disulfide	2	4	3	4	3	3	*	*	Sulfury, sweaty, onion	MS + RI
15	755	Unknown	2	5	–	–	–	–	***	***	Oily, onion	
16	810	Hexanal	7	9	8	7	8	9	NS	NS	Green, fruity	MS + RI
17	909	Heptanal	3	–	–	–	–	–	***	***	Fruity, nutty,	MS + RI
18	915	Methional	6	5	5	5	5	5	NS	NS	Meaty, oily, burnt	MS + RI
19	984	Dimethyl trisulfide	3	11	11	10	10	10	**	**	Sulfury, burnt, onion	ms + ri
20	994	2-Octanone	10	5	–	–	–	–	***	*	Fruity, fresh	ms + ri
21	1021	Octanal	4	–	–	3	–	2	NS	NS	Fruity, green	ms + ri
22	1038	2-Acetylthiazole	3	–	–	–	–	–	*	*	Burnt, onion	ms + ri
23	1055	2-Octenal	3	–	–	–	2	–	*	*	Earthy	ms + ri
24	1094	Unknown	3	2	–	–	2	2	NS	NS	Meaty, onion, burnt	
25	1117	Unknown	4	2	–	2	–	–	*	*	Meaty, onion	
26	1148	2-Nonenal	9	7	–	–	4	3	**	NS	Earthy, fermented, burnt	ms + ri
27	1170	2,3-Diethyl-5-methylpyrazine	6	11	2	3	4	5	***	**	Meaty, nutty, burnt	ms + ri
28	1203	2,4-Nonadienal	10	3	7	6	6	3	*	***	Meaty, burnt, chocolate	MS + RI
29	1246	Benzothiazole	3	2	4	3	3	3	NS	NS	Burnt, meaty	ms + ri
30	1268	Unknown	3	–	–	–	–	–	***	***	Meaty	

[a] On BPX5 column (60 m × 0.32 mm, 1.0 μm).
[b] NS, $P > 0.05$; *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$.
[c] MS + RI, mass spectra agree with those of authentic compounds; ms + ri, mass spectra identified using NIST/EPA/NIH mass spectral database and RI agrees with literature values; ms, mass spectrum agrees with spectrum in NIST/EPA/NIH mass spectral database.
[d] RI below 500, the first alkane detected was pentane.

Strecker degradation of leucine contributes to the formation of 3-methylbutanal. It has been hypothesized that 3-methylbutanal was probably one of the compounds responsible for roasted beef flavour (Specht & Baltes, 1994). Somewhat lower detection frequencies were found for methional (meaty, oily, burnt), octanal (fruity, green), unknown compound **24** (meaty, onion, burnt) and benzothiazole (burnt, meaty) with no significant influence of breed and diet. Methional, the Strecker aldehyde produced from methionine, is an important sulfur compound present in cooked beef. It has been described as "cooked potatoes" and meaty (Gasser & Grosch, 1988; Specht & Baltes, 1994). Lipid degradation of oleic and linoleic acids produces octanal, adding a fruity, green note to the aroma profile of shallow-fried beef (Specht & Baltes, 1994). Benzothiazole is produced by means of a Maillard reaction. It has been previously described as pyridine-like and metallic (Gasser & Grosch, 1988), and stewed, gravy and gas (Machiels et al., 2003) in cooked beef, and as burnt, roasted and rubbery in yogurt (Ott, Fay, & Chaintreau, 1997). Among the odour-active compounds showing no different detection frequencies through the meats, methional, compound **24** and benzothiazole exhibited a clear meat-like aroma. So, they seemed to contribute to the development of a desirable meat flavour in cooked beef meat. Hydrogen sulfide and carbon disulfide were characterised by a sulfury odour. They probably acted, in synergism with other compounds, to help in developing a desirable overall aroma in cooked beef meat. Hexanal and octanal contributed to the green and fruity notes of the aroma profile while 3-methylbutanal added a chocolate note and 2,3-butanedione a caramel note to the overall odour of cooked beef meat.

3.3. Effect of breed

The aroma composition of the cooked beef meat was affected by breed when the animals were fed similar diets. Twenty one compounds were significantly influenced by breed ($p < 0.05$), ten of which were Maillard reaction products, five derived from lipids and seven were not identified. Methanethiol, dimethyl disulfide and dimethyl trisulfide are derived from sulfur-containing amino acids; 2-methylpropanal and 2-methylbutanal are products of Strecker degradation of valine and isoleucine, respectively. The Maillard reaction is also responsible for the formation of 2-butanone, ethyl acetate, 2,3-pentanedione, 2-acetylthiazole and 2,3-diethyl-5-methylpyrazine. The autoxidation of oleic and linoleic acid produced heptanal, 2-octenal and 2-nonenal (Elmore et al., 1999). Linoleic and arachidonic acids are partially autoxidised during cooking with the formation of several volatiles, one of which is 2,4-nonadienal (Gasser & Grosch, 1988). Lipid degradation also contributes to the formation of 2-octanone.

Nine compounds possessed an odour activity in the BB meat only, including 2-butanone (chocolate, buttery), ethyl acetate (chemical), compounds **9** (fruity), **10** (meaty, fruity, chocolate) and **15** (oily, onion), heptanal (fruity), 2-octanone (fruity, fresh), 2-acetylthiazole (burnt, onion) and compound **30** (meaty). Those compounds could contribute to produce a different overall odour by adding their specific notes to the aroma profile of BB meat. For instance, 2-acetylthiazole has been described as an important contributor to the roasty note of cooked beef (Gasser & Grosch, 1988). Methanethiol (sulfury, sweaty) and compound **25** (meaty, onion) were found in BB and Lim meat while 2-octenal (earthy), compound **24** (meaty, onion, burnt) and 2-nonenal (earthy, fermented, burnt) were only present in BB and AA meats. Among these, there were no significantly different detection frequency scores between BB and Lim/AA for 2-octenal and compound **24**; BB had significantly higher detection frequency scores than Lim and AA for the other compounds. 2-Methylpropanal (burnt, nutty, oily) was only detected in Lim and AA; compound **1** (chemical, fruity, fresh), 2-methylbutanal (nutty, burnt, onion), 2,3-pentanedione (caramel, buttery, fruity), dimethyl disulfide (sulfury, sweaty, onion), dimethyl trisulfide (sulfury, burnt, onion), 2,3-diethyl-5-methylpyrazine (meaty, nutty, burnt) and 2,4-nonadienal (meaty, burnt, chocolate) possessed odour activities in the three breeds at significantly different levels.

Methanethiol, ethyl acetate, 2-octanone, and 2,3-diethyl-5-methylpyrazine seemed to be major contributors to the aroma profile of BB meat, adding sulfury, chemical, fruity and meaty notes while 2-methylpropanal had an important impact on the burnt, nutty and oily notes of Lim and AA meats. Dimethyl trisulfide and 2,4-nonadienal contributed, at different levels, to the sulfury and meaty notes of the meats while compound **1** had a high chemical, fruity and fresh impact on the profile of AA meat. Based on those results, it seems that meat from BB developed a wider range of odour-active compounds. BB is generally considered as a lean beef meat with the correlated loss of flavours, but in this study, it seems that BB meat developed many more volatile compounds than Lim or AA meats. This could be due to the fact that BB is characterized by a double-muscle conformation with related effect on the chemical composition of the meat. Double-muscle condition is known to affect sensorial properties of meats (Campo, Sanudo, Panea, Alberti, & Santolaria, 1999). Furthermore, the differences in odour development amongst the three breeds are also supported by different intramuscular fat and protein contents (Table 3). The meat from BB had the highest level of crude protein and the lowest level of intramuscular fat; the meat of AA presented the opposite trends while the meat of Lim was characterized by intermediate data. The proportion of unsaturated fatty acids was higher for BB than for the two other

Table 3
Chemical composition of beef meat (*longissimus thoracis*) from Belgian Blue (BB), Limousin (Lim) and Aberdeen Angus (AA) bulls offered a pulp- or cereal-based diet; data are from Bultot, Dufrasne, Clinquart, Hoquette, and Istasse (2002)

Composition (%)[a]	BB		Lim		AA	
	Pulp	Cereal	Pulp	Cereal	Pulp	Cereal
Crude protein	86.5a	86.6a	81.0b	83.3b	77.0c	77.6c
Ether extract	2.8a	2.4a	6.8b	6.3b	9.9c	10.3c
Cholesterol	1.3	1.5	1.6	1.4	1.5	1.4

[a] Meat composition in percentage of dry matter, compositions with different letters are significantly different ($p < 0.05$).

breeds because BB meat contains more membrane phospholipids. The relative ratios of the different fatty acids were also different through the breeds.

From these findings, it seems that breed has an important influence on generation of odour-active compounds during cooking. This different balance of volatiles through the breeds could lead to a different overall aroma. However, the reasons for the different aroma profiles remain unclear. This could be due to the complexity of the matrix, cross-reactions between Maillard-derived products and lipid degradation products, and/or specific mechanisms of formation within a breed.

3.4. Effect of diet

No significant differences were observed in the intramuscular fat content, pH fall after slaughter or cholesterol and protein contents when animals were fed the two different fattening diets within a breed (Bultot et al., 2002). However, sixteen aroma compounds were significantly affected by the diet, out of which seven were produced by Maillard reactions, four from lipid degradation and five were unknown compounds. For BB, 16 compounds showed different detection frequency scores. Among these, 12 presented higher scores when the animals were fed the pulp-based diet. For Lim, four compounds had higher scores for the pulp-based diet and one for the cereal-based diet. Two compounds showed higher detection frequency scores in the pulp-based diet fed AA and one when the animals were fed the cereal-based diet.

Methanethiol presented higher detection frequency scores and dimethyl sulfide lower scores when BB and Lim were fed the pulp-based diet. For BB and AA, 2-octenal showed higher scores for the pulp-based diet. The three breeds had lower detection frequency scores for 2,3-diethyl-5-methylpyrazine and higher scores for 2,4-nonadienal when the animals were fed the pulp-based diet.

Eleven compounds presented higher detection frequency scores for the pulp-based diet, four presented lower scores and there was no clear effect for two compounds. Overall, it seems that the pulp-based diet induced the development of more of the odour-active compounds detected in this study.

Evidently, the diet essentially affected BB. The effect of diet on the detection frequency scores was less pronounced or not present for Lim and AA meats. This could be due to the fact that the intramuscular fat content in BB was lower than in Lim and AA. As a consequence, small changes in fat content and composition could induce larger changes in terms of quantity and nature of detected odour-active compounds. However, no straightforward reasons could explain such observations. From this study, it seems that differences in the potency or the presence of key odour-active compounds could not be fully explained by differences in common chemical composition parameters, such as fat and protein content and composition. It is therefore suggested that more complex interactions and mechanisms could be involved in the formation of specific key odour-active compounds.

4. Conclusions

The volatile compounds of beef meat, originating from differently fed BB, Lim and AA, were extracted using a model mouth system. Their odour activity was evaluated by GC-O. Thirty compounds possessed an odour activity in cooked beef. Significant influences of breed and diet on the development of the odour-active compounds of cooked beef meat were observed. The meat of BB seemed to generate more odour-active compounds and seemed to be more influenced by the feeding diet. This could be, at least in part, the consequence of its double-muscle condition and correlated specific chemical processes. However, no obvious explanation could be given to explain the trends observed. Complex cross-reactions and mechanisms could be involved in the formation of specific key odour-active compounds for a given breed/diet combination. Additional work has to be done to better understand the specific aroma development in different cattle breeds and the influence of diet on their aroma profiles, especially as far as BB is concerned.

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References

Acree, T. E. (1993). Gas chromatography-olfactometry. In C. T. Ho & C. Manley (Eds.), *Flavor measurement* (pp. 77–94). New York: Dekker.

Berdagué, J. L., Monteuil, P., Montel, M. C., & Talon, R. (1993). Effect of starter cultures on the formation of flavour compounds in dry sausage. *Meat Science, 35*, 275–287.

Bultot, D., Dufrasne, I., Clinquart, A., Hoquette, J. L., Istasse, L. (2002). Performances and meat quality of Belgian Blue, Limousin and Aberdeen Angus bulls fattened with two types of diet. In Proceedings of the 9ème Renc. Rech. Ruminant, Paris, p. 271.

Campo, M. M., Sanudo, C., Panea, B., Alberti, P., & Santolaria, P. (1999). Breed type and ageing time effect on sensory characteristics of beef strip loin steaks. *Meat Science, 51*, 383–390.

Carrapiso, A. I., Ventanas, J., & Garcia, C. (2002). Characterisation of the most odor-active compounds of Iberian ham headspace. *Journal of Agricultural and Food Chemistry, 50*, 1996–2000.

Cerny, C., & Grosch, W. (1992). Evaluation of potent odorants in roasted beef by aroma extract dilution analysis. *Zeitschrift für Lebensmittel-Untersuchung und Forschung, 194*, 322–325.

Elmore, J. S., Mottram, D. S., Enser, M., & Wood, J. D. (1999). Effect of polyunsaturated fatty acid composition of beef muscle on the profile of aroma volatiles. *Journal of Agricultural and Food Chemistry, 47*, 1619–1625.

Elmore, J. S., Mottram, D. S., Enser, M., & Wood, J. D. (2000). The effects of diet and breed on the volatile compounds of cooked lamb. *Meat Science, 55*, 149–159.

Gasser, U., & Grosch, W. (1988). Identification of volatile flavour compounds with high aroma values from cooked beef. *Zeitschrift für Lebensmittel-Untersuchung und Forschung, 186*, 489–494.

Grosch, W. (1993). Detection of potent odorants in foods by aroma extract dilution analysis. *Trends in Food Science and Technology, 4*, 68–73.

Guillard, A.-S., Le Quere, J.-L., & Vendeuvre, J.-L. (1997). Emerging research approaches benefit to the study of cooked cured ham flavour. *Food Chemistry, 59*, 567–572.

Guth, H., & Grosch, W. (1994). Identification of character impact odorants of stewed beef juice by instrumental analyses and sensory studies. *Journal of Agricultural and Food Chemistry, 42*, 2862–2866.

Kerscher, R., & Grosch, W. (1997). Comparative evaluation of potent odorants of boiled beef by aroma extract dilution and concentration analysis. *Zeitschrift für Lebensmittel-Untersuchung und Forschung, 204*, 3–6.

Kondjoyan, N., & Berdagué, J. L. (1996). *A compilation of relative retention indices for the analysis of aromatic compounds*. Saint-Genes Champanelle: Edition du Laboratoire Flaveur.

Machiels, D., Clinquart, A., Eppe, G., Dotreppe, O., Depauw, E., & Istasse, L. (2000). Caractéristiques et techniques d'analyse des odeurs de la viande cuite. *Annales de Médecine Vétérinaire, 144*, 279–287.

Machiels, D., Istasse, L. (2002). Solid Phase Microextraction for the isolation of volatile flavour compounds in cooked beef meat. In Proceedings of the 48th International Congress of Meat Science and Technology, Rome, vol. 1, 2002, pp. 262–263.

Machiels, D., van Ruth, S. M., Posthumus, M. A., Istasse, L. (2003). Gas-chromatography-olfactometry analysis of the volatile compounds of two commercial Irish beef meats. Talanta 60, 755–764.

Marsili, R. T., & Miller, N. (2000). Determination of major impact compounds in fermented cucumbers by solid-phase microextraction-gas chromatography-mass spectrometry-olfactometry detection. *Journal of Chromatographic Science, 38*, 307–314.

Maruri, J. L., & Larick, D. K. (1992). Volatile concentration and flavor of beef as influenced by diet. *Journal of Food Science, 57*, 1275–1281.

Monin, G. (1991). Facteurs biologiques des qualités de la viande bovine. *INRA Productions Animales, 4*, 151–160.

Ott, A., Fay, L., & Chaintreau, A. (1997). Determination and origin of the aroma impact compounds of yogurt flavour. *Journal of Agricultural and Food Chemistry, 45*, 850–858.

Pollien, P., Ott, A., Montigon, F., Baumgartner, M., Munoz-Box, R., & Chaintreau, A. (1997). Hyphenated headspace-gas chromatography-sniffing technique:screening of impact odorants and quantitative aromagram comparisons. *Journal of Agricultural and Food Chemistry, 45*, 2630–2637.

Ruiz, J., Cava, R., Ventanas, J., & Jensen, M. (1998). Headspace SPME for the analysis of volatiles in a meat product: dry-cured iberian ham. *Journal of Agricultural and Food Chemistry, 46*, 4688–4694.

Specht, K., & Baltes, W. (1994). Identification of volatile flavor compounds with high aroma values from shallow-fried beef. *Journal of Agricultural and Food Chemistry, 42*, 2246–2253.

van Ruth, S. M. (2001). Methods for gas chromatography-olfactometry: a review. *Biomolecular Engineering, 17*, 121–128.

van Ruth, S. M., & O'Connor, C. H. (2001). Evaluation of three gas chromatography-olfactometry methods: comparison of odour intensity-concentration relationships of eight volatile compounds with sensory headspace data. *Food Chemistry, 74*, 341–347.

van Ruth, S. M., & Roozen, J. P. (1994). Gas chromatography/sniffing port analysis and sensory evaluation of commercially dried bell peppers (Capsicum annuum) after rehydration. *Food Chemistry, 51*, 165–170.

van Ruth, S. M., & Roozen, J. P. (2000). Influence of mastication and saliva on aroma release in a model mouth system. *Food Chemistry, 71*, 339–345.

van Ruth, S. M., Roozen, J. P., & Cozijnsen, J. L. (1994). Comparison of dynamic headspace mouth model systems for flavour release from rehydrated bell pepper cuttings. In H. Maarse & D. G. van der Heij (Eds.), *Trends in flavour research* (pp. 59–64). Amsterdam: Elsevier Science.

Wasserman, A. E. (1979). Symposium on meat flavor: chemical basis for meat flavor. *Journal of Food Science, 44*, 6–11.