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Fat volatiles tracers of grass feeding in sheep

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Abstract

Volatile compounds were analysed in subcutaneous fat from lambs raised and finished on grass (GG); raised and finished on concentrates (SS); raised on grass and finished on concentrates for a long (GS1) or a short (GS2) period. Whereas 3-methylindole (skatole), a compound that has been described as a good discriminator of grass feeding, was unaffected by the diet ($P > 0.05$), 2,3-octanedione was lower ($P < 0.01$) in the fat from animals that spent a period in stall with a concentrate diet than in those finished on grass. Among the 20 monoterpenes detected, only *p*-cymene was affected by the treatment, being higher ($P < 0.05$) in the fat from animals raised and finished on grass (GG) than in the other treatments. Eight among the 13 detected sesquiterpenes were affected by the diet treatment. In particular β-caryophyllene, not detected in the fat from animals raised and finished on concentrates (SS group), was at basal levels in the animals raised on pasture and finished for different durations on concentrates (GS1 and GS2 treatments) and was present at high levels in the animals raised and finished on grass ($P < 0.0005$). From a factorial discriminant analysis, four of the 33 terpenes detected discriminated perfectly those animals raised and finished on pasture (GG) from all the other groups (SS, GS1, GS2).

Keywords: Sheep; Pasture; Terpene; β-Caryophyllene; 2,3-Octanedione; Tracer techniques

1. Introduction

Meat from lambs grazing grass as opposed to animals fed concentrates has a different flavour (Rousset-Akrim, Young, & Berdagué, 1999), colour (Priolo, Micol, Agabriel, Prache, & Dransfield, 2002) and fatty acid composition (Enser et al., 1998). Recent studies (Enser et al., 1998; Nürnberg et al., 2001) have demonstrated that meat from ruminants grazing grass has a fatty acid composition thought to be more beneficial to human health, compared with animals fed concentrate diets. Efforts have been made in recent years to enable tracing grass feeding directly in the herbivore products. Different methods, based on spectrophotometric properties of fat (Prache & Theriez, 1999; Priolo, Prache, Micol, & Agabriel, 2002) or lean (Cozzolino, De Mattos, & Martinos, 2002) have been proposed. Other authors (Piasentier, Valusso, Camin, & Versini, 2003) used the ratio of stable isotopes to verify meat origin.

A volatile compound, 2,3-octanedione, has been reported as an excellent marker of pasture diets (Suzuki & Bailey, 1985; Young, Berdagué, Viallon, Rousset-Akrim, & Theriez, 1997). Young et al. (1997) found also 3-methylindole (skatole) to be present at higher concentrations in the fat from animals grazing grass compared to those fed concentrates. Some plant secondary metabolites, such as mono- and sesquiterpenes, can be transferred from forage to meat (Larick et al., 1987) and dairy products (Moio, Rillo, Ledda, & Addeo, 1996; Viallon et al., 1999) and have been proposed as biomarkers of grass feeding in animal products (Mariaca et al., 1997; Cornu et al., 2001).

The objectives of the present trial were (i) to compare 2,3 octanedione, skatole, mono- and sesquiterpenes in the fat from lambs raised on pasture and finished for different durations on concentrates; and (ii) to evaluate the possibility of using these compounds in meat products as indicators of grass feeding.

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2. Materials and methods

This trial was conducted at the experimental farm of INRA, Clermont-Ferrand- Theix (France).

2.1. Experimental design

Four feeding treatments were compared: grass feeding at pasture (GG); stall feeding (SS); grass-feeding followed by a long stall-finishing period (GS1); grass-feeding followed by a short stall-finishing period (GS2).

2.2. Animals and diets

Forty male Ile de France lambs born in spring (3 April 2001 $\pm$ 7 days) were divided into two groups of 10 and 30 animals on 18 April. The first 10 lambs represented the SS group and were penned indoor in a multiple box with their dams. The remaining 30 lambs were allowed to graze natural pasture with their mothers. On 17 June, ten of the grazing lambs, representative of the flock variability with respect to their live weights and plasma carotenoid concentrations (Prache, Priolo, & Grolier, 2003), were penned indoors in a multiple box. These lambs represented the GS1 group. On 9 July, 10 grazing lambs were again chosen on the basis of their live weight and plasma carotenoid concentrations and allocated to a multiple box indoor (GS2 group). The remaining 10 lambs (GG) were allowed to graze for the duration of the trial. All the lambs were weaned at age 77 days. The lambs penned indoors were fed 85% commercial concentrate and 15% hay on an as-fed basis. The quantity of food given to the indoor lambs was regulated weekly to give similar growth rates between groups.

2.3. Pasture botanical composition

The botanical composition of the pasture was, on a dry matter basis: *Lolium perenne* (29.9%), *Dactylis glomerata* (28.7%), *Festuca arundinacea* (20.8%), *Taraxacum officinale* (10.1%), *Bromus sterilis* (9.9%), *Trifolium repens* (0.7%) and *Ranunculus macrophyllus* (0.3%).

2.4. Slaughter procedures

When the first animals attained 34.5 kg, slaughtering began and took place every 14 days and on each occasion, all animals weighing close to or more than 34.5 kg were slaughtered. About 40 g of subcutaneous caudal fat were taken immediately after slaughter, wrapped in aluminium foil, vacuum packed and stored at -20 °C.

2.5. Analysis of volatiles

Analyses were performed on 6 animals per treatment. A subsample of 0.15 g adipose tissue was taken from the interior of each sample and placed in a 35 ml glass extractor. Volatile compounds were extracted by dynamic headspace using a Tekmar LSC 2000 (Cincinnati, OH 45234, USA) in the following conditions: prepurge 5 min, pre-heat 25 min at 110 °C; purge 60 min at 110 °C with an helium flux of 95 ml min^{-1}, trap on Tenax at 35 °C. Dry purge, 5 min at 35 °C, desorb preheat 175 °C; desorb 5 min at 180 °C, cool-down at -150 °C in the column head. Injection, 2 min at 250 °C.

Volatile compounds were separated by a gas chromatograph Hewlett-Packard 5890 (F-91947 Les Ulis, France) with a Supelco (CH-1196 Gland, Switzerland) SPB5 capillary column (length 60 m; internal diameter, 0.32 mm; phase thickness 1μm) using helium as carrier gas (1 ml min^{-1}). The temperature was programmed as follows: 40 °C for 5 min with an increase of 3 °C min^{-1} up to 230 °C (2 min).

Compounds were detected using a Hewlett-Packard 5971A electron impact mass spectrometer. Identifications were done by comparing the experimental mass spectra with those contained in the NIST/EPA/MSDC Mass spectral Database, 1996 (National Institute of Standards and Technology, Gaithersburg, MD 20899, USA). The retention indices (Tranchant, 1982) were compared to those compiled by Kondjoyan and Berdagué (1996). The integrations were performed by the software Chemstation (Hewlett Packard). Terpene peak integrations were performed on their specific ions (93 and 136 for monoterpenes; 93, 136, 161 and 204 for sesquiterpenes).

2.6. Statistical analysis

Data were analysed by ANOVA using the group treatment as experimental factor. Single animals were considered as experimental units. When the ANOVA was significant ($P < 0.05$), means were separated by the Least Significant Difference test. Terpene amounts were normalised relative to the total terpene area. Variance of the data of skatole and 2,3-octanedione was stabilised using logarithmic transformation. Correlation analysis and factorial discriminant analysis were performed using Statistica software (Statsoft Inc., Tulsa, OK, USA).

3. Results

3.1. Animal performance

The age at which the animals reached the target slaughter weight (34.5 kg) did not differ between treatments ($P = 0.27$) and was on average 126 days. As expected, the average daily gain from birth to slaughter was unaffected by treatment with an overall mean of 233 g days^{-1}. Warm carcasses weighed on average 15.0

kg with no significant treatment effect. The stall-finishing period lasted on average 42 days for the GS2 and 48 days for the GS1 animals, but with a great variability leading the GS1 group to overlap the GS2 group.

3.2. Volatile compounds

Skatole was detected in all the 24 samples and although it tended to be higher in the GG group, it was not significantly different between groups (Table 1; $P = 0.15$). On the other hand, 2,3-octanedione was much higher ($P < 0.0005$) in the fat from animals raised and finished on pasture (GG) than in the other three groups, GS1 and GS2 being intermediate. The correlations between the logarithmic values for 2,3-octanedione and the time spent on stall ($r = -0.88$) or on pasture ($r = 0.85$) during the trial were highly significant ($P < 0.0005$).

Monoterpenes and sesquiterpenes detected in the samples are presented in Table 2. Among the 19 monoterpenes detected, 11 were identified. Among the 13 sesquiterpenes detected, 11 were identified. The only monoterpene significantly ($P < 0.05$) affected by the diet was *p*-cymene, which tended to be higher in the fat from animals raised and finished on grass. The correlation between this compound and the time spent in stall ($r = -0.45$) was significant ($P < 0.05$). Many sesquiterpenes were decidedly affected by the treatment. In particular α- and β-cubebene were increased 4-fold in the fat from animals raised on grass compared to those raised or just finished in stall ($P < 0.0005$). β-caryophyllene was much higher in animals raised and finished on grass (GG) than in those raised on grass and finished on concentrates ($P < 0.0005$). This sesquiterpene was not detected in the samples from animals raised and finished in stall (SS group). The opposite result was obtained for β-gurjunene, that was 50–80 times higher in the animals finished in stall than in those fed pasture (GG). Finally, *trans*-cadina-1(6),4-diene was present in the fat from animals raised and finished on grass and was at basal level in all the others groups ($P < 0.0005$).

Table 1
Skatole and 2,3 octanedione in sheep fat[a]

	Treatment				SEM	*P*-Value
	SS	GS1	GS2	GG		
No of lambs	6	6	6	6		
Skatole	5.71	5.81	5.90	6.19	0.08	0.149
2,3 octanedione	6.46c	6.96b	6.88b	7.72a	0.17	<**0.0005**

Within a row, values with different letters are significantly different ($P < 0.05$).
[a] Logarithmic values of area arbitrary units.

Table 2
Monoterpenes and sesquiterpenes desorbed from sheep fat[a]

	LRI[b]	Treatment				SEM	*P* value
		SS	GS1	GS2	GG		
No of lambs		6	6	6	6		
Monoterpenes							
α-Pinene	943	8.48	8.88	10.05	8.38	1.040	0.947
Sabinene	982	0.66	0.65	0.75	1.16	0.099	0.213
β-Pinene	988	1.88	1.89	0.70	1.35	0.346	0.606
M4	1003	1.05	0.71	0.95	0.95	0.086	0.593
α-Phellandrene	1020	2.47	2.34	2.82	2.30	0.251	0.898
α-Terpinene	1025	0.40	0.27	0.32	0.12	0.049	0.244
p-Cymene	1033	0.38b	0.26b	0.43ab	0.64a	0.049	**0.032**
Limonene + β-phellandrene	1038	9.83	21.20	9.25	12.39	3.160	0.541
Eucalyptol	1043	0.39	0.22	0.39	0.47	0.046	0.248
γ-Terpinene	1060	3.66	2.33	4.27	3.95	0.340	0.198
Linalool	1102	1.67	1.29	1.79	1.88	0.179	0.682
M13	1121	1.18	0.84	1.18	0.64	0.129	0.375
M14	1126	1.54	0.85	1.70	0.76	0.196	0.220
M15	1163	5.97	3.82	6.02	8.85	0.712	0.089
M16	1177	1.57	1.55	1.52	1.86	0.171	0.902
M17	1204	2.46	1.66	2.63	3.05	0.262	0.310
M18	1266	2.21	1.25	1.54	3.00	0.349	0.302
M19	1359	2.15	1.57	2.18	1.40	0.242	0.592
Sesquiterpenes							
α-Cubebene	1404	0.98b	0.60b	1.23b	4.25a	0.377	<**0.0005**
4a-α-,7-α-7a-α-Nepetalactone	1411	0.68	0.36	0.63	0.55	0.063	0.299
β-Cubebene	1416	0.55b	0.25b	0.42b	2.04a	0.173	<**0.0005**
Longifolene	1430	0.96	0.65	0.89	0.85	0.099	0.744
α-Gurjunene	1448	5.15	3.49	4.81	4.03	0.400	0.473
β-Caryophyllene	1456	0.00b	0.04b	0.90b	13.49a	1.450	<**0.0005**
Geranyl acetone	1459	8.90	7.26	18.77	7.38	2.260	0.221
S8	1463	1.68ab	1.07b	2.01a	2.13a	0.140	**0.021**
β-Gurjunene	1471	30.7a	33.64a	18.99a	0.39b	3.590	**0.001**
S10	1489	0.02b	0.02b	0.00b	0.29a	0.040	**0.002**
trans-Cadina-1(6),4-diene	1517	0.07b	0.02b	0.33b	7.52a	0.869	<**0.0005**
β-Bisabolene	1527	0.87	0.38	0.80	1.48	0.154	0.079
zonarene	1550	1.26b	0.65c	1.58ab	2.17a	0.165	**0.003**

Within a row, values with different letters are significantly different ($P < 0.05$)
[a] Area values normalized relative to the total terpene area for each individual chromatogram.
[b] Linear retention indices.

4. Discussion

Previous studies report skatole in the fat from lambs raised on grass at higher levels compared to animals fed concentrates (Young et al., 1997). Skatole is an unpleasant odorous compound and is a product of tryptophan degradation (Priolo, Micol, & Agabriel, 2001). According to Sheath, Coulon, and Young (2001), the high protein/non-fibrous carbohydrate ratio typical of grass diets enhances protein deamination by rumen microbes and would therefore be responsible for high levels of skatole in fat from ruminants fed grass. Young, Lane, Priolo, and Fraser (2003) slaughtered male Romney

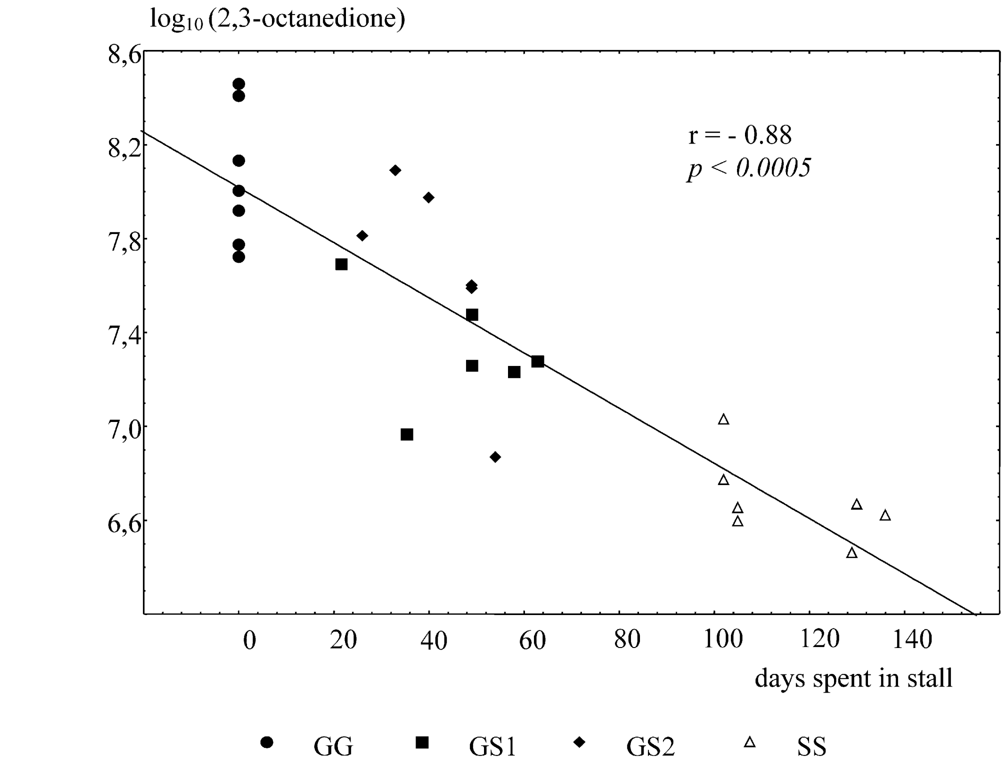

Fig. 1. Regression between the time spent in stall (days) and the log value of 2,3-octanedione.

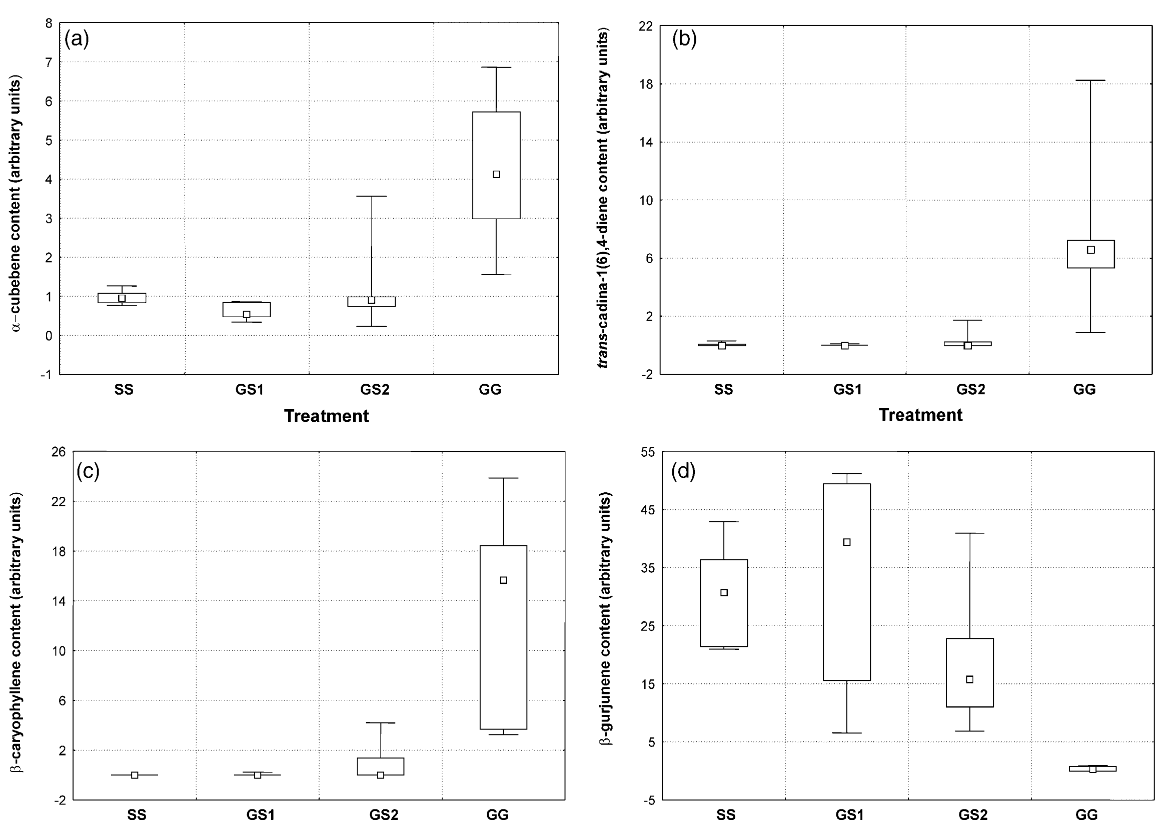

Fig. 2. Box-plot presentation of volatile compounds values, with maximum, minimum, median and quartile distribution, in groups of lambs raised on grass (GG), finished on stall for a short (GS1) or a long (GS2) period, or raised and finished in stall (SS): (a) α-cubebene, (b) *trans*-cadina-1(6),4-diene, (c) β-caryophyllene, (d) β-gurjunene.

lambs at 132 and 232 days of age after grazing or receiving concentrates. They found higher levels of skatole in grass-fed lambs at 132 days and much less difference at 232 days. Differences in breed and precocity, and also in the location of fat sampling could have played a role: Young et al. (2003) measured skatole in the perirenal fat, while in this study it was measured in the subcutaneous caudal fat.

In agreement with Young et al. (1997), 2,3-octanedione proved to be an excellent indicator of pasture feeding: the highest value found in animals raised and finished on concentrates (SS) was still lower than the lowest value found for the animals raised and finished on pasture (GG). The crude value for 2,3-octanedione in the GG group averaged 25 times that of the SS group. Moreover, this compound decreased when the stall-finishing period increased (Fig. 1). Young et al. (1997) hypothesized that 2,3-octanedione might be related to the enzyme lipoxygenase, absent in corn and abundant in leafy plants. Lipoxygenase is also present in soybeans (an ingredient of our stall diet) (Keen & Wilson, 1992), which would explain why 2,3-octanedione was found (at very low levels) even in the animals fed concentrates during the whole duration of the trial (SS group). According to Elmore, Campo, Enser, and Mottram (2002), 2,3-octanedione could be formed by linoleic acid oxidation on heating. In the present case, however, although the samples were heated to 110 °C during analysis, this was performed in an oxygen free atmosphere.

Terpenes, present in very minute amounts compared to the fat major compounds, were detected thanks to the high concentrating power of the dynamic headspace technique. They were however difficult to identify. The only monoterpene affected by the diet treatment was *p*-cymene. This compound has been shown to be transferred from forage to cheese (Viallon et al., 1999).

Several sesquiterpenes were highly affected by the diet. α- (Fig. 2 a) and β-cubebene were increased four fold in the GG treatment and were detected in all the treatments, even in the SS animals. Most of the terpenes for which significant differences were observed between treatments were present at similar levels in the GS1, GS2 and SS groups and were higher in the GG group. In addition, the variability in the GG group was generally very high, making it difficult to rely on such compounds to trace pasture feeding. This was the case for *trans*-cadina-1(6),4-diene (Fig. 2b). Special attention should be paid to β-caryophyllene, which was never detected in the samples from the animals raised and finished on concentrates (SS). Moreover, as shown in Fig. 2c there was no overlapping for this compound

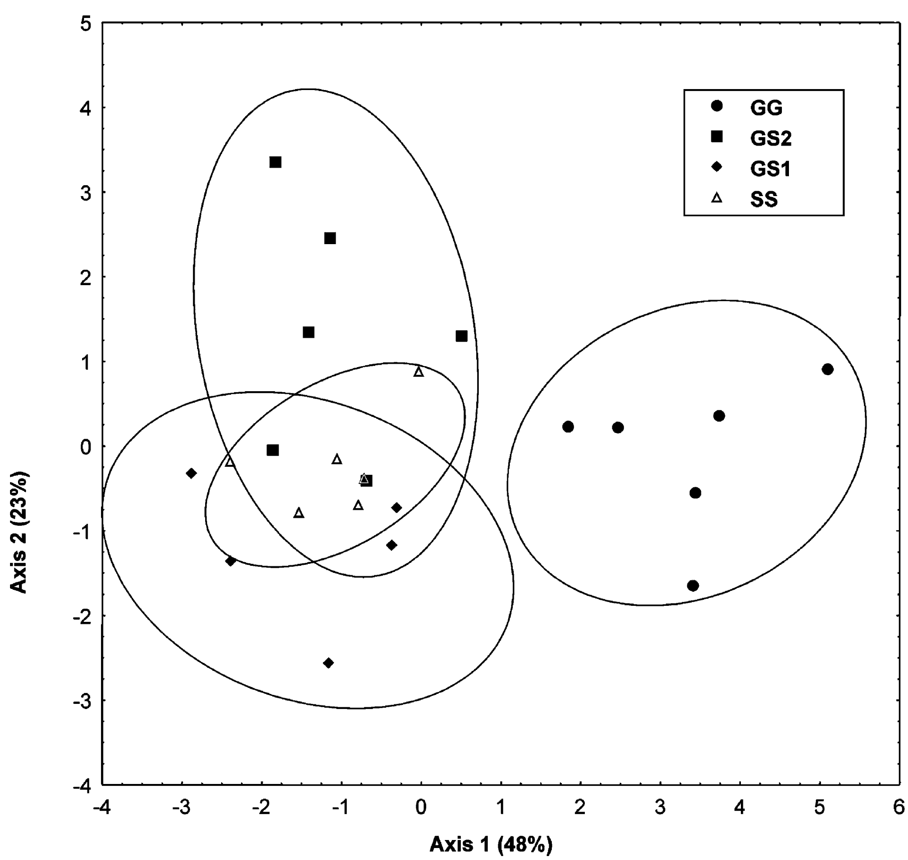

Fig. 3. Factorial discriminant analysis of four terpenes (β-cubebene, β-gurjunene, S8 and geranyl acetone) that discriminate animals fed exclusively pasture (GG) from all the other animals.

between the animals fed pasture for the duration of the trial (GG) and the animals fed pasture and finished for a longer period on stall (GS1). This compound was detected (and at very low level) only in one of the six GS1 animals. It was detected only in two of six GS2 animals, and only one of the GS2 animals had a value higher than the lowest value found in the GG group. One advantage of using β-caryophyllene as a biomarker of grass feeding would be that this sesquiterpene is widespread in nature (Clericuzio, Alagona, Ghio, & Toma, 2000). In a work that examined the distribution of mono- and sesquiterpenes in 47 plants from high- and lowland pastures of Switzerland, Mariaca et al. (1997) found this compound in 6 different families (Apiaceae, Asteraceae, Campanulaceae, Geraniaceae, Lamiaceae and Rubiaceae). Cornu et al. (2001) detected β-caryophyllene at early and late stages in grassland plants. The huge difference in the presence of this compound between the animals raised and finished on grass (GG) on one hand, and those raised on grass and finished on concentrates (GS1, GS2) on the other, could have occurred because: (i) β-caryophyllene was deposited even in these latter animals and then metabolised or otherwise eliminated during the period in the stall; (ii) it was deposited even in these latter animals and then diluted with fat of new formation; (iii) β-caryophyllene was not yet deposited in these animals (GS1 and GS2), and the GG animals had high value of this compound because of a deposition in the last period before slaughtering. Further research should be employed to clarify this point.

Only one compound, β-gurjunene, was higher in the fat from animals finished in stall compared to those finished on pasture. As shown in Fig. 2d there was no overlapping for the content of this compound between the animals fed and finished on pasture (GG) and the others (GS1, GS2 and SS). This compound was on average eighty times more concentrated in the GG animals than the stall-fed ones.

A factorial discriminant analysis revealed four terpenes (β-cubebene, β-gurjunene, S8 and geranyl acetone) that discriminated animals fed exclusively pasture (GG) from all the other animals (Fig. 3). It is interesting to note that these molecules are not those found to be significantly different between groups or significantly correlated with the time spent in stall. On the contrary, geranyl acetone remained relatively constant from one individual to another. Thus, by normalising data, a part of the signal information is lost, but other information arises, well adapted to discriminate between groups.

5. Conclusions

Although pastures rich in monocotyledons are considered to have low terpene contents (Mariaca et al., 1997), great differences were found in the sesquiterpene profile of fat from lambs raised and finished on a pasture containing 90% of graminaceae, and those fed concentrates. One sesquiterpene, β-caryophyllene, was found to be highly represented in the fat from animals raised and finished on pasture whereas it was not detected in the samples from animals raised and finished on concentrates. This compound could therefore be proposed as biomarker of grass feeding in meat products, as already suggested by Mariaca et al. (1997) for cheese. A factorial discriminant analysis allowed us to identify four terpenes that discriminate animals fed exclusively pasture from those finished for different durations on concentrates. Considering the importance of the phenological stage of the plants on volatile compounds (Mariaca et al., 1997), similar studies should be undertaken in different periods of the year. In this experiment, 2,3-octanedione was the compound best related to the length of the stall-finishing period.

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