Effect of nutritional factors on fatty acid composition of lamb fat deposits

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Abstract

A literature review was made of the influence of nutritional factors on the fatty acid composition of fat deposits and muscles of lambs. A bibliographic data base, containing 979 observations from 108 papers, was made up in such way that one observation corresponded to one group of lambs in one experiment. Each nutritional factor was studied only when number of observations was sufficient. Consequently, special emphasis was given to the effect of dietary ingredients supplying energy or nitrogen on the fatty acid composition of subcutaneous (SC) and perirenal adipose (PR) tissues and in muscles of lambs. Regardless of sex, breed and breeding conditions, all the tissues examined showed a similar pattern of modification in fatty acid composition with diets. In milk fed lambs the pattern of fatty acids largely reflected the dietary fat pattern. The fatty acid of stored fats before weaning had an influence on fatty acid composition of fat deposits and muscle, several months after weaning. When the diets were rich in beet pulp or in fish meal the proportion of C\textsubscript{18:1} was significantly increased and the proportions of C\textsubscript{18:0}, C\textsubscript{18:2} and C\textsubscript{18:3} decreased in fat tissues. Inclusion of maize in diet resulted in an increase in linoleic acid content in fat deposits. Inclusion of cotton meal increased linoleic and stearic acids in fat deposits. Grass-based diets increased C\textsubscript{18:0} and C\textsubscript{18:3} in lamb tissues. Melting point of both SC and PR were strongly associated with differences in C\textsubscript{18:0} percentages. This approach underlined difficulties in understanding the diet effects on fatty acid composition of fat deposits and muscles without taking feeding and other management aspects into account. This study supported the extent to the modification of the fatty acid composition of lamb carcasses by choice of dietary ingredients despite the ruminal hydrogenation of dietary fat.

Résumé

Effets des facteurs nutritionnels sur la composition en acides gras des dépôts adipeux d’agneaux. L’influence des facteurs nutritionnels sur la composition en acides gras a été étudiée à partir des données de la littérature. Une base de données bibliographiques de 979 observations provenant de 108 articles a été élaborée de telle sorte qu’une observation corresponde à un groupe d’animaux dans une expérience. Chaque facteur nutritionnel étudié devait disposer d’un nombre suffisant d’observations. De ce fait, un accent particulier a été mis sur les effets des matières premières, incorporées comme source d’énergie ou d’azote, sur la composition en acides gras des dépôts adipeux sous-cutanés (SC), périrénaux (PR), et des muscles des agneaux. Indépendamment du sexe, de la race et des conditions d’élevage, les tissus étudiés ont présenté, selon le régime alimentaire, des modifications similaires de profils de composition en acides gras. Les acides gras déposés avant le sevrage influencent la composition des acides gras des dépôts adipeux et des muscles plusieurs mois après le sevrage.

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Lorsque les rations sont riches en pulpes de betteraves ou en farine de poisson, la proportion de C\textsubscript{18:1} est significativement augmentée dans les tissus alors que les proportions de C\textsubscript{18:0}, C\textsubscript{18:2} et C\textsubscript{18:3} sont abaissées. L’incorporation de maïs dans la ration induit une augmentation de la teneur en acide linoléique dans les dépôts adipeux. L’incorporation de tourteau de coton induit un accroissement des teneurs en acides stéarique et linoléique dans les tissus des agneaux. Les rations à base d’herbe conduisent à des teneurs élevées en C\textsubscript{18:0} et en C\textsubscript{18:3} dans les dépôts adipeux des agneaux. Les variations du point de fusion des tissus sous-cutané et péritonéal sont fortement associées à celles des teneurs en C\textsubscript{18:0}. Cette approche souligne les difficultés pour comprendre les effets d’un régime alimentaire sur la composition des dépôts gras et des muscles lorsque l’on ne prend pas en compte tous les aspects de l’alimentation et de l’élevage. Bien que les lipides alimentaires soient fortement hydrogénés dans le rumen, cette étude montre l’amplitude des modifications des proportions des différents acides gras dans les carcasses d’agneaux qui dépend du choix des aliments de la ration. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Lamb; Fat deposits; Muscles; Fatty acid composition; Diet; Energy sources; Nitrogen sources

1. Introduction

Adipose deposits strongly influence the quality of ruminant carcasses through their amount and composition. The effects of nutritional factors on the proportion and body distribution of adipose deposits have been reviewed by Vézihet and Prud’hon (1975), Kempster (1981), Robelin (1986) and Bas (1993).

Nutritional factors have a lesser influence on the fatty acid composition of adipose tissues and muscles in ruminants than in monogastrics because of the low lipid content of their diet and of the hydrogenation of dietary lipids in the rumen (Wood and Enser, 1997; Nürnberg et al., 1998). Research on this topic has been brought up to date again due to negative consequences of ruminant fats in human dietetics. Studies on growing lambs have mostly focused on the effects of concentrate or fat levels and the type of cereals and fats added in diets. They have also aimed at analysing the effects of nutritional factors on meat organoleptic parameters, such as flavour and juiciness, (Melton, 1990), or the occurrence of defects in firmness or colour of subcutaneous adipose tissues and meat (Ørskov et al., 1974; L’Estrange and Mulvihill, 1975; Cazes et al., 1990).

Some of these studies have shown that sheep present a specificity due to the influence of feeding on the fat composition of their carcasses, with a particularly high proportion of odd-numbered and branched-chain fatty acids (Duncan et al., 1974; Bas et al., 1980, 1998).

The aim of this work was to analyse the effects of the type of diet, energy and protein sources, and feeding programs on the fatty acid composition of lamb adipose tissues and muscles from available bibliographic data.

2. Material and methods

Our work first consisted in selecting articles dealing with fatty acid composition of lamb adipose deposits and muscles, with a stress on those analysing the effects of dietary factors or having other objectives but supplying enough information on diets and feeding management. All the papers were taken except when they did not provide sufficient information in one of the five following languages: English, French, German, Italian or Spanish.

A data base was thus made up in such way that one observation corresponded to one group of lambs in one experiment. All observations were characterised by explained variables (fatty acids of adipose tissues and muscles, characteristics of adipose deposits such as melting point and softness index) and variables related with the animals, breed, live weight, age, sex, etc., and with the diets or the feeding management, type and composition of diets, duration of milk feeding period or post-weaning period. The variables of the data base, corresponding to the main animal characteristics, are reported in Table 1.

The fatty acid composition of seven tissues: subcutaneous (SC), perirenal (PR), omental (OM), mesenteric (ME), intermuscular (IN), intramuscular (MU), and whole carcass (Car) were analysed. The locations of SC samples were, in decreasing order of number of observations: the back (8th–12th rib),...
Table 1
Main animal characteristics of the data base

<table>
<thead>
<tr>
<th>Sex</th>
<th>n</th>
<th>ADG (g/day)</th>
<th>Weaning age (WA) (weeks)</th>
<th>Slaughter LW (SLW) (kg)</th>
<th>Slaughter age (SA) (weeks)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>425</td>
<td>0&lt;ADG&lt;100</td>
<td>20</td>
<td>190</td>
<td>0&lt;WA&lt;5</td>
</tr>
<tr>
<td>F</td>
<td>136</td>
<td>10&lt;ADG&lt;150</td>
<td>69</td>
<td>340</td>
<td>5&lt;SLW&lt;20</td>
</tr>
<tr>
<td>C</td>
<td>174</td>
<td>150&lt;ADG&lt;200</td>
<td>73</td>
<td>35</td>
<td>20&lt;SLW&lt;30</td>
</tr>
<tr>
<td>Mixed sexes</td>
<td>152</td>
<td>200&lt;ADG&lt;250</td>
<td>122</td>
<td>25</td>
<td>30&lt;SLW&lt;40</td>
</tr>
<tr>
<td></td>
<td></td>
<td>250&lt;ADG&lt;300</td>
<td>157</td>
<td>10</td>
<td>40&lt;SLW&lt;50</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ADG&gt;300</td>
<td>74</td>
<td>10</td>
<td>SLW&gt;50</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>ADG (g/day)</th>
<th>Weaning age (WA) (weeks)</th>
<th>Slaughter LW (SLW) (kg)</th>
<th>Slaughter age (SA) (weeks)</th>
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</thead>
<tbody>
<tr>
<td>M</td>
<td>425</td>
<td>0&lt;ADG&lt;100</td>
<td>20</td>
<td>190</td>
<td>0&lt;WA&lt;5</td>
</tr>
<tr>
<td>F</td>
<td>136</td>
<td>10&lt;ADG&lt;150</td>
<td>69</td>
<td>340</td>
<td>5&lt;SLW&lt;20</td>
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<tr>
<td>C</td>
<td>174</td>
<td>150&lt;ADG&lt;200</td>
<td>73</td>
<td>35</td>
<td>20&lt;SLW&lt;30</td>
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<tr>
<td>Mixed sexes</td>
<td>152</td>
<td>200&lt;ADG&lt;250</td>
<td>122</td>
<td>25</td>
<td>30&lt;SLW&lt;40</td>
</tr>
<tr>
<td></td>
<td></td>
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<td>157</td>
<td>10</td>
<td>40&lt;SLW&lt;50</td>
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<tr>
<td></td>
<td></td>
<td>ADG&gt;300</td>
<td>74</td>
<td>10</td>
<td>SLW&gt;50</td>
</tr>
</tbody>
</table>

a Sex: M, entire males; F, females; C, castrated males; mixed sexes, entire males + castrated males or entire males + females or castrated males + females
b ADG, average daily gain; LW, live weight; n, number of observations.

dock (tail basis), costal, leg, inguinal and sternal regions, the Semimembranosus and Triceps Brachii, and around the fat tail. The information on the fatty acid composition of MU came most frequently from Longissimus dorsi, then from Semimembranosus (Table 3) and lastly from Triceps Brachii.

The variables concerning diet components were the type of forage and the main energy, protein, and fat sources in concentrates or in complete diets. Other variables, when not provided in the articles, were calculated from available information such as the proportion of roughage and concentrate in diets, metabolisable energy, total protein, crude fibre, and fat contents of the complete diets and concentrates, while missing nutritive values were assessed using the INRA tables of feedstuff values (Andrieu et al., 1989).

During milk- and post-weaning periods, ten types of diets were distinguished: ewes’ milk, milk replacer, ewes’ milk and concentrate, ewes’ milk and pasture, roughage alone, pasture alone, roughage and concentrate, pasture and concentrate, concentrate alone, complete diet. The two latter diets were defined by using thresholds for the proportions of main feedstuffs. For example, diets were classified in complete diets when the mixed diets contained more than 25% of chopped or ground roughage, but in concentrate alone diet if they contained less than 25% of roughage. In the same way, the diet was classified as roughage and concentrate when the authors had mentioned a supply of raw straw (unground or unchopped), and was classified as concentrate alone when no straw supply was reported. The bibliographic data base thus formed contained 979 observations from 108 papers.

Data were analysed by the Factor, GLM, REG and Nlin procedures of SAS (SAS, 1987). The GLM procedure was used with the factors most frequently represented.

3. Results

3.1. General characteristics of adipose tissues and muscles

The fatty acid composition of three adipose tissues frequently mentioned in the data base, namely subcutaneous, omental, perirenal, and that of one intramuscular tissue are reported in Table 2. In these tissues three main fatty acids (C\textsubscript{16:0}, C\textsubscript{18:0}, and C\textsubscript{18:1}) represented the major part of FA (from 78% in MU to 87% in OM). The coefficients of variation of C\textsubscript{16:0} and C\textsubscript{18:1} proportions by weight were lower (CV = 18.5 and 14.2%, respectively) than that of C\textsubscript{18:0} (CV = 40%). The intra-tissue variability for C\textsubscript{16:0} and C\textsubscript{18:1} was approximately 10%, but was far greater for C\textsubscript{18:0} (reaching 20% in PR and 37% in SC).

Principal component analyses were performed on overall adipose tissues (Fig. 1A), SC (Fig. 1B), PR (Fig. 1C), MU (Fig. 1D) to study the relationship between main fatty acid percentages. The first two factor axes expressed about 45% of the total variance in overall adipose tissues, SC and MU, but about 60% in PR. Fig. 1A showed, on the first factor, an
Table 2
Mean fatty acid composition of the main fat deposits in lambs

<table>
<thead>
<tr>
<th>Fat deposits</th>
<th>C&lt;sub&gt;14:0&lt;/sub&gt;</th>
<th>C&lt;sub&gt;16:0&lt;/sub&gt;</th>
<th>C&lt;sub&gt;18:0&lt;/sub&gt;</th>
<th>C&lt;sub&gt;16:1&lt;/sub&gt;</th>
<th>C&lt;sub&gt;18:1&lt;/sub&gt;</th>
<th>C&lt;sub&gt;18:2&lt;/sub&gt;</th>
<th>C&lt;sub&gt;18:3&lt;/sub&gt;</th>
<th>C&lt;sub&gt;17:0&lt;/sub&gt;</th>
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<tbody>
<tr>
<td>SC</td>
<td>4.8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>23.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>15.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>40.8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.4&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>PR</td>
<td>4.0&lt;sup&gt;b&lt;/sup&gt;</td>
<td>20.6&lt;sup&gt;b&lt;/sup&gt;</td>
<td>26.1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.7&lt;sup&gt;b&lt;/sup&gt;</td>
<td>36.7&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.9&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.5&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.9&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>OM</td>
<td>4.6&lt;sup&gt;a,b&lt;/sup&gt;</td>
<td>23.7&lt;sup&gt;a,c&lt;/sup&gt;</td>
<td>29.9&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.9&lt;sup&gt;a,b,c&lt;/sup&gt;</td>
<td>33.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.3&lt;sup&gt;a,b&lt;/sup&gt;</td>
<td>0.8&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.1&lt;sup&gt;a,b&lt;/sup&gt;</td>
</tr>
<tr>
<td>MU</td>
<td>3.8&lt;sup&gt;c&lt;/sup&gt;</td>
<td>22.5&lt;sup&gt;c&lt;/sup&gt;</td>
<td>15.6&lt;sup&gt;c&lt;/sup&gt;</td>
<td>3.2&lt;sup&gt;c&lt;/sup&gt;</td>
<td>40.4&lt;sup&gt;c&lt;/sup&gt;</td>
<td>6.3&lt;sup&gt;c&lt;/sup&gt;</td>
<td>1.1&lt;sup&gt;c&lt;/sup&gt;</td>
<td>1.4&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup>SC, subcutaneous adipose tissue (250<sub>x</sub>x<sub>y</sub> 411); PR, perirenal adipose tissue (111<sub>x</sub>x<sub>y</sub> 219); OM, omental adipose tissue (7<sub>x</sub>x<sub>y</sub> 17); MU, intramuscular fat (86<sub>x</sub>x<sub>y</sub> 143); x, number of observations for each fatty acid.

<sup>b</sup>Superscripts a, b and c, means in a column with different superscripts were significantly different (P<0.05).

The relationship between the melting point (MP) and the percentage of the main fatty acids was studied in SC and PR. The softness index (SI) was studied in SC only, and most particularly in samples from the dorsal region. The SI values were standardised on a scale varying from 1 (very firm) to 5 (very soft and oily). On the whole, the MP was linked to the same acids in PR and in SC. The coefficients of correlation between the MP and the percentages of C<sub>16:0</sub> and C<sub>18:0</sub> were significant and positive (r = 0.32, P < 0.05 and 0.87, P < 0.001, in PR, 40 < n < 49, and r = 0.38, P < 0.01, r = 0.88, P < 0.001, in SC, 49 < n < 58, respectively). They were significant and negative between the MP and the percentages of C<sub>16:1</sub>, C<sub>18:1</sub>, and C<sub>18:2</sub> (−0.60, P < 0.001; −0.54, P < 0.001; −0.62, P < 0.001, in PR, and −0.63, P < 0.001; −0.42, P < 0.01; −0.40, P < 0.01, in SC, respectively). Moreover, in PR the variations of the MP and C<sub>14:0</sub> percentage were negatively correlated (r = −0.33, P < 0.05) and in SC, MP was significantly in opposition to odd-numbered and branched-chain fatty acid percentages. For these two tissues, the MP was best explained from the C<sub>18:0</sub> percentage, with a coefficient of determination over 75% (Fig. 2). The two prediction equations became not significantly different when the C<sub>18:0</sub> and the C<sub>18:2</sub> percentages were used simultaneously as explicit variables.

MP (°C) = 0.51 · C<sub>18:0</sub> − 0.28 · C<sub>18:2</sub> + 29.0;

(R<sup>2</sup> = 0.86, RSD = 1.7, n = 101)

For one group of animals, the mean difference in MP between the PR and SC from caudal region, which approximatively represented 75% of the SC samples, analysed for MP, was about 6.4°C.

The SI was less closely linked to fatty acid proportion than was the MP probably because of its more subjective estimation and the important variability of SC composition according to sampling sites. In SC, the C<sub>16:0</sub> percentage was the variable which predicted SI best. Taking into account a second fatty acid percentage in the equation improved slightly but not significantly the prediction of the SI.

SI = −0.22 · C<sub>16:0</sub> + 7.3;

(R<sup>2</sup> = 0.40, RSD = 0.75, n = 67)

3.2. Variation of fatty acid composition due to sampling site

Although there were change in lipid content and in fatty acid composition in omental adipose tissue according to tissue site (Bas et al., 1992), the precise
Fig. 1. Principal component analyses showing relationship between main fatty acid content in all fat deposits (A) or in subcutaneous adipose tissue (B), or in perirenal adipose tissue (C), or in intramuscular fat (D).
even-numbered saturated fatty acids. But the C\textsubscript{18:1} percentage was clearly higher in leg than in back samples.

In spite of the low representivity of the Semimembranosus, one may say it was characterised by higher percentages of unsaturated fatty acids (C\textsubscript{16:1}, C\textsubscript{18:1}, C\textsubscript{18:2}, and C\textsubscript{18:3}) and by a lower percentage of C\textsubscript{18:0} than Longissimus dorsi.

As variability in compositions was related to sampling sites, and as the number of samples available varied from one site to another, because of the higher number of samples indicated in Table 3, the back site of SC and the Longissimus dorsi site of MU were favourably considered to study the effects of diets on the fatty acid composition of tissues.

3.3. Effect of milk feeding on the adipose tissue composition

As shown in Table 4 (ewes’ milk fed lambs) and in comparison with Tables 5 and 6 (weaned lambs), the fatty acid composition of tissues from lambs fed ewe milk was characterised by lower percentages of C\textsubscript{18:2}, C\textsubscript{18:3}, and C\textsubscript{18:1} and higher percentages of C\textsubscript{14:0}, C\textsubscript{16:0}, and C\textsubscript{18:0} than that of tissues from lambs slaughtered after weaning. In the most cases, the composition of adipose tissues reflected the fatty acid composition of ewe milk which is rich in C\textsubscript{14:0} and C\textsubscript{16:0} in comparison to post-weaning diets. The percentages of total saturated fatty acids did not differ between SC and PR, but SC had a lower C\textsubscript{18:0} percentage and higher C\textsubscript{14:0} and C\textsubscript{16:0} percentages than PR. During the milk feeding period, the C\textsubscript{18:1}...
### Table 4
Fatty acid composition from three fat deposits in lambs fed ewe milk

<table>
<thead>
<tr>
<th>Fat deposits</th>
<th>C_{14:0}</th>
<th>C_{16:0}</th>
<th>C_{18:0}</th>
<th>C_{16:1}</th>
<th>C_{18:1}</th>
<th>C_{18:2}</th>
<th>C_{18:3}</th>
<th>C_{17:0}</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC</td>
<td>9.4^a</td>
<td>24.8^a</td>
<td>11.7^a</td>
<td>4.0^a</td>
<td>40.0^a</td>
<td>3.1^a</td>
<td>0.8^a</td>
<td>1.5^a</td>
</tr>
<tr>
<td>PR</td>
<td>6.8^b</td>
<td>22.2^b</td>
<td>17.1^b</td>
<td>2.9^b</td>
<td>40.2^b</td>
<td>3.8^b</td>
<td>1.2^b</td>
<td>1.5^b</td>
</tr>
<tr>
<td>MU</td>
<td>6.6^c</td>
<td>21.7^c</td>
<td>13.0^c</td>
<td>2.3^c</td>
<td>40.4^c</td>
<td>5.9^c</td>
<td>1.4^c</td>
<td>1.0^c</td>
</tr>
</tbody>
</table>

^a SC, subcutaneous adipose tissue (12<n<18); PR, perirenal adipose tissue (4<n<8); MU, intramuscular fat (n=6); n, number of observations for each fatty acid. Superscripts a and b, means in a column with different superscripts were significantly different (P<0.05).

### Table 5
Effects of types of diets on the mean fatty acid composition of three fat deposits in lambs

<table>
<thead>
<tr>
<th>Diets</th>
<th>Fatty acids</th>
<th>C_{14:0}</th>
<th>C_{16:0}</th>
<th>C_{18:0}</th>
<th>C_{16:1}</th>
<th>C_{18:1}</th>
<th>C_{18:2}</th>
<th>C_{18:3}</th>
<th>C_{17:0}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pasture</td>
<td>4.2^a</td>
<td>21.5^b</td>
<td>23.6^a</td>
<td>2.8^c</td>
<td>36.9^a</td>
<td>4.2^a</td>
<td>2.4^a</td>
<td>1.2^a</td>
<td></td>
</tr>
<tr>
<td>Past + conc.</td>
<td>3.4^b,^c</td>
<td>21.5^b</td>
<td>22.6^a</td>
<td>3.7^b</td>
<td>37.4^b</td>
<td>5.2^b,c</td>
<td>1.5^b</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Rough + conc.</td>
<td>3.6^b,^c</td>
<td>21.9^b</td>
<td>17.6^b</td>
<td>3.0^c</td>
<td>39.5^c</td>
<td>5.1^b</td>
<td>0.5^c</td>
<td>2.6^b</td>
<td></td>
</tr>
<tr>
<td>Concentrate</td>
<td>2.9^a</td>
<td>20.4^b</td>
<td>17.7^b</td>
<td>3.7^b</td>
<td>41.5^c</td>
<td>6.1^c</td>
<td>0.7^c</td>
<td>2.3^b</td>
<td></td>
</tr>
<tr>
<td>Complete diet</td>
<td>3.6^b</td>
<td>23.4^c</td>
<td>19.9^c</td>
<td>2.7^c</td>
<td>38.2^c</td>
<td>6.4^c</td>
<td>2.0^b</td>
<td>2.1^c</td>
<td></td>
</tr>
</tbody>
</table>

^a SC, subcutaneous adipose tissue from the mid back area; PR, perirenal adipose tissue; MU, muscle (Longissimus dorsi). Pasture, pasture alone (21<n<45); Past + conc., pasture and concentrate (8<n<12); Rough + conc., roughage and concentrate (57<n<78); Concentrate, concentrate alone (161<n<236); complete diet, mixed compound diet with roughage and concentrate (64<n<120); n, number of observations for each fatty acid. Superscripts a–d, LS means in a column with different superscripts were significantly different (P<0.05); the LS means of the five diets was calculated for three adipose tissues.

### Table 6
Effects of three types of diets on fatty acid composition of three fat deposits in lambs

<table>
<thead>
<tr>
<th>AD</th>
<th>Diets</th>
<th>Fatty acids</th>
<th>C_{14:0}</th>
<th>C_{16:0}</th>
<th>C_{18:0}</th>
<th>C_{16:1}</th>
<th>C_{18:1}</th>
<th>C_{18:2}</th>
<th>C_{18:3}</th>
<th>C_{15:0}</th>
<th>C_{17:0}</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC</td>
<td>Rough + conc.</td>
<td>3.2^a</td>
<td>21.6^a</td>
<td>11.7^a</td>
<td>3.7^b</td>
<td>40.8^b</td>
<td>3.7^a</td>
<td>0.4^a</td>
<td>1.3^c</td>
<td>3.4^a</td>
<td>3.1^a</td>
</tr>
<tr>
<td>Concentrate</td>
<td>3.4^a</td>
<td>20.9^a</td>
<td>15.8^a</td>
<td>4.1^a</td>
<td>42.5^a</td>
<td>5.6^b</td>
<td>0.8^b</td>
<td>0.8^b</td>
<td>2.7^b</td>
<td>1.6^b</td>
<td></td>
</tr>
<tr>
<td>Complete diet</td>
<td>4.7^b</td>
<td>24.9^b</td>
<td>16.2^b</td>
<td>3.2^b</td>
<td>39.0^b</td>
<td>6.0^b</td>
<td>2.2^b</td>
<td>1.1^c</td>
<td>2.6^b</td>
<td>1.5^b</td>
<td></td>
</tr>
<tr>
<td>PR</td>
<td>Rough + conc.</td>
<td>3.6^a</td>
<td>20.6^a</td>
<td>26.2^a</td>
<td>2.5^a</td>
<td>36.2^a</td>
<td>4.7^a</td>
<td>0.4^a</td>
<td>0.5^b</td>
<td>2.4^a</td>
<td>0.9^a</td>
</tr>
<tr>
<td>Concentrate</td>
<td>2.7^b</td>
<td>19.2^b</td>
<td>24.1^b</td>
<td>3.1^b</td>
<td>40.0^b</td>
<td>5.4^a</td>
<td>0.7^a</td>
<td>0.6^a</td>
<td>2.2^a</td>
<td>1.0^a</td>
<td></td>
</tr>
<tr>
<td>Complete diet</td>
<td>3.1^b</td>
<td>21.3^a</td>
<td>27.5^b</td>
<td>2.7^b</td>
<td>35.6^a</td>
<td>6.6^b</td>
<td>2.6^b</td>
<td>–</td>
<td>2.4^a</td>
<td>0.6^b</td>
<td></td>
</tr>
<tr>
<td>MU</td>
<td>Rough + conc.</td>
<td>4.0^a</td>
<td>23.6^a</td>
<td>14.7^a</td>
<td>2.7^c</td>
<td>41.9^a</td>
<td>7.0^a</td>
<td>0.5^b</td>
<td>0.6^b</td>
<td>2.0^a</td>
<td>1.4^a</td>
</tr>
<tr>
<td>Concentrate</td>
<td>2.9^b</td>
<td>20.8^b</td>
<td>13.3^b</td>
<td>4.2^b</td>
<td>41.0^b</td>
<td>7.2^a</td>
<td>0.5^b</td>
<td>0.6^b</td>
<td>1.9^a</td>
<td>1.5^a</td>
<td></td>
</tr>
<tr>
<td>Complete diet</td>
<td>2.0^b</td>
<td>23.1^a</td>
<td>17.0^c</td>
<td>2.0^c</td>
<td>40.5^b</td>
<td>5.5^b</td>
<td>0.8^b</td>
<td>–</td>
<td>1.1^b</td>
<td>–</td>
<td></td>
</tr>
</tbody>
</table>

^a AD, adipose tissues; SC, subcutaneous adipose tissue from the mid back area; PR, perirenal adipose tissue; MU, muscle (Longissimus dorsi). Diets for SC: Rough + conc. (15<n<24); concentrate (49<n<78); complete diet (14<n<55); diets for PR, rough + conc. (18<n<30); concentrate (4 9<n<109); complete diet (8<n<40); diets for MU, rough + conc. (11<n<29); concentrate (38<n<49); complete diet (10<n<18); n, number of observations for each fatty acid; Superscripts a,b,c, means in a column with different superscripts were significantly different (P<0.05).
Fig. 3. Effect on age of the \( C_{18:1} \) content of fat deposits in milk fed lambs.

content in SC, PR, and MU (Fig. 3) regularly decreased with the age of lambs by about 1% per week, whereas \( C_{16:1} \) and \( C_{18:2} \) contents increased.

As with ewe milk, the fatty acid percentages of adipose tissues from milk-replacer fed lambs varied with the lipid composition of milk replacers (Fig. 4). Increasing the \( \text{C}_{12:0} \) supply in milk increased the tissular content in \( \text{C}_{12:0} \) but also in \( \text{C}_{14:0} \) and \( \text{C}_{16:0} \). Likewise, an increase in the \( \text{C}_{16:0} \) content in milk replacers increased the \( \text{C}_{16:0} \), \( \text{C}_{18:0} \) and \( \text{C}_{18:1} \) percentages in tissues. Moreover, an increase in \( \text{C}_{18:3} \) in milk replacers had favourable repercussions on the \( \text{C}_{18:3} \) and in \( \text{C}_{18:2} \) percentages in tissues. Thus, knowledge of fatty acid percentages in milk replacers made predictions of the fatty acid composition in tissues possible with a confidence interval of between 70 and 99%, for \( \text{C}_{18:0} \) and \( \text{C}_{18:2} \), respectively.

After weaning, with the diets normally offered to lambs, the percentage of \( \text{C}_{14:0} \) gradually decreased in all tissues whereas the percentages of long-chain saturated fatty acids, particularly \( \text{C}_{18:0} \), increased (Fig. 5). This probably resulted from the low short- and medium-chain fatty acid percentages and the high percentage of total \( \text{C}_{18} \) acids in post-weaning diets and the hydrogenation potential of the unsaturated \( \text{C}_{18} \) acids in the rumen. The fatty acid profile of tissues, which reflects the milk feeding period, gradually disappeared after weaning.

3.4. Influence of post-weaning feeding

3.4.1. Effects of the type of diets

Table 5 reports the mean fatty acid composition of three tissues (SC, PR, and MU) in lambs fed with five types of diets: two diets based on grazing on pasture, with or without concentrate, and three diets distributed indoors (roughage and concentrate, complete diet and concentrate alone). The roughage alone diet was not mentioned because the number of observations was too low (n = 6). The differences in
fatty acid composition of tissues between the types of diets was relatively limited although significant. Extreme concentrations were observed with the pasture alone and concentrate alone diets.

With the pasture alone diet, tissues were richer in C≤14:0, C≤18:0 and C≤18:3 and poorer in C≥18:1, C≥18:2 and C≥17:0. In lambs reared on pasture alone, the C≥18:3 percentage in all three tissues was relatively high (2.7, 2.6, and 1.7%, in SC, PR, and MU, respectively). The percentage of polyunsaturated fatty acids (PUFA) of the n-3 series in MU was also high and at least twice that from lambs fed the roughage and concentrate diet. This high n-3 PUFA percentage had repercussions on the n-3 PUFA/n-6 PUFA ratio in MU.

Table 6 presents the fatty acid compositions of tissues obtained with the most commonly used diets. Generally, the type of diet tended to have similar effects on the fatty acid composition, regardless of anatomical location of the fat deposit. For example SC, PR and MU from lambs receiving the complete diet were all characterised by a lower C≥18:1 percentage and a higher percentage of C≥18:3 and total saturated fatty acids than with other diets. In SC, the variability of the C≥18:0 percentage reached nearly twice that of other tissues (CV=33, 19, and 15%, respectively for SC, PR, and MU). In SC again, the percentage of C≥18:0 was relatively low whereas those of odd-numbered and branched-chain fatty acids were high. The concentrate alone diet presented the highest C≥18:1 percentage and lowest percentage of total saturated fatty acids. On the whole, the pasture alone and pasture and concentrate diets on the one hand and concentrate alone and roughage and concentrate diets on the other hand resulted in very similar compositions in each tissue.

When crude protein (CP), crude fibre (CF) ether extract (EE) and energy values of diets were taken into account, the coefficients of determination of most fatty acid percentages, except C≥14:0, were strongly increased. With these variables and when considering the tissue and diet effects, the coefficients of determination of the percentages of the main fatty acids were increased from 27, 57, and 17% to 55, 65, and 35%, for C≥16:0, C≥18:0, and C≥18:1, respectively. The richest diets in terms of metabolisable energy were generally associated with the lowest C≥18:0, C≥18:1 and C≥18:2 percentages and the highest C≥16:0, C≥16:1, C≥15:0 and C≥17:0 percentages in SC, PR, and MU. With higher crude protein content in diets lamb tissues were poorer in C≥16:0 and in C≥18:0 and richer in C≥16:1, C≥18:1 and C≥18:3. The increasing crude fibre content in diets were associated with increase in C≥18:0 percentage and with decrease in C≥18:2 percentage in tissues. The ether extract contents of diets were negatively correlated with the percentages of C≥16:0, C≥18:3, C≥15:0 and C≥17:0 and positively correlated with C≥18:0 percentages in tissues. Moreover, in SC the metabolisable energy density of the diets was significantly (P<0.001) opposed to the percentage of C≥18:0, but positively correlated with that of odd-numbered and branched-chain fatty acids. An increase in dietary fat content slightly reduced the C≥18:3, C≥16:1, and C≥17:0 percentages in SC, PR and MU, but more markedly the sum of odd-numbered and that of the branched-chain fatty acid percentages in SC.
Table 7
Effects of the main sources of energy of the concentrate on the fatty acid composition of lamb fat deposits.

<table>
<thead>
<tr>
<th>Energy source</th>
<th>Fatty acids</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C&lt;sub&gt;14:0&lt;/sub&gt;</td>
</tr>
<tr>
<td>Beet pulp</td>
<td>3.1&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Barley</td>
<td>3.1&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Maize</td>
<td>3.1&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Wheat</td>
<td>3.5&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>1</sup> Beet pulp (n=8); Barley (31<n<92); Maize (33<n<131); Wheat (5<n<18); n, number of observations for each fatty acid. Superscripts a,b,c, LS means in a column with different superscripts were significantly different (P<0.05); The LS means of the four sources of energy was calculated for three adipose tissues, SC: subcutaneous adipose tissue from the mid-back area, PR: perirenal adipose tissue, MU: muscle (Longissimus dorsi).

3.4.2. Energy sources

The energy sources of the concentrates or the complete diets significantly influenced the percentages of most fatty acids. The C<sub>18:2</sub> and C<sub>18:3</sub> percentages in tissues were higher when maize was the main energy supply (Table 7) probably because it has a higher fat content than the other energy sources and because of its high C<sub>18:2</sub> content. As shown in Fig. 6, the C<sub>18:2</sub> percentage in SC, PR, and MU increased as the proportion of maize increased in the diet, whereas the C<sub>16:0</sub> percentage decreased. Beet pulp decreased the percentages of saturated fatty acids (C<sub>16:0</sub> and C<sub>18:0</sub>) in tissues, in the same way as with semi-synthetic diets based on glucose or starch (Tove and Matrone, 1962; Duncan and Gar-}

ton, 1971). The similarity between the compositions of all tissues from lambs receiving semi-synthetic diets or beet pulp based diets could be the result of the low fat contents of these two diets. Thus, in both cases the fatty acids in the tissues do not originate from the diets but from a de novo synthesis. The tissues of lambs fed diets rich in wheat had a low percentage of C<sub>18:1</sub> and high percentages of saturated fatty acids. A rise in the level of incorporation of barley or maize in the diets led to significant increases in C<sub>17:0</sub> percentages in SC, PR, and MU, and a significant decrease in the C<sub>18:0</sub> in SC.

3.4.3. Protein sources

Ingredients included in diets to increase their protein contents may also influence the fatty acid composition of adipose tissues and muscles of lambs (Table 8). Addition of cotton meal as the main protein source brought about a significant raise in C<sub>18:0</sub> and C<sub>18:2</sub> percentages in tissues, probably because of the high content of total unsaturated C<sub>18</sub> acids in cotton lipids. But when lambs received complete, concentrate alone or roughage and concentrate diets rich in cotton meal, the tissues had low C<sub>18:3</sub>, C<sub>18:1</sub> and C<sub>16:0</sub> contents. These effects persisted when crude protein, crude fibre, and ether extract content were at even levels in the diets. When incorporating fish meal in lamb diets, C<sub>18:0</sub> and C<sub>18:2</sub> percentages in the tissues were reduced, whereas C<sub>18:1</sub> percentage was increased. Alfalfa meal, rich in linolenic acid, induced a higher percentage of C<sub>18:3</sub> in tissues than the three other protein sources shown in Table 8. When the proportion of alfalfa meal was increased in a diet, C<sub>16:1</sub>, C<sub>18:1</sub> and C<sub>18:2</sub> percentages were generally lower in tissues. But, as shown by Fig. 7, the decrease in the C<sub>18:1</sub> percentage seemed
Table 8
Effects of the main sources of nitrogen of the concentrate on the fatty acid composition of lamb fat deposits

<table>
<thead>
<tr>
<th>Energy source</th>
<th>Fatty acids</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C₁₄:₀</td>
</tr>
<tr>
<td>Alfalfa meal</td>
<td>3.1ᵃ</td>
</tr>
<tr>
<td>Soybean meal</td>
<td>3.2ᵃ</td>
</tr>
<tr>
<td>Cotton meal</td>
<td>3.3ᵃ</td>
</tr>
<tr>
<td>Fish meal</td>
<td>2.9ᵃ</td>
</tr>
</tbody>
</table>

¹ Soybean meal (18<n<66); alfalfa meal (20<n<115); fish meal (6<n<18); cotton meal (12<n<16); n, number of observations for each fatty acid. Superscripts a, b and c, LS means in a column with different superscripts were significantly different (P<0.05). The LS means of the four sources of nitrogen was calculated for three adipose tissues, SC: subcutaneous adipose tissue from the mid back area, PR: perirenal adipose tissue, MU: muscle (Longissimus dorsi).

Fig. 7. Relation between the C₁₈:₁ content of adipose tissues and muscles and the alfalfa content of the solid diets. C₁₈:₁ SC= 38.6+0.24x−0.0035x², RSD=2.4; n=57; C₁₈:₁ PR=31.0+0.37x−0.0048x², RSD=2.9; n=42; C₁₈:₁ MU=51.2−0.22x−0.0013x², RSD=1.74; n=12.

4. Discussion

4.1. Content of the data base

The analysis of bibliographic data on the fatty acid composition of adipose tissues and muscles of lambs presented some difficulties because the number of records differed widely between fatty acids, tissues and diets. The number of missing data for the main fatty acids varied from 52 for C₁₈:₀ to 338 for C₁₈:₃ and reached 423, 528, and 331 for the odd-numbered fatty acids: C₁₅:₀, C₁₇:₀, and C₁₇:₁, respectively.

The type of diet could be defined for nearly 95% of the observations but the type of roughage and the main sources of energy and nitrogen could not be defined for 40–50% of the observations. The chemical compositions of the concentrate alone and complete diets were determined in more than 80% of the cases but the chemical composition of post-weaning diets could be estimated in only 70% of the cases because information about the unprocessed roughage/concentrate ratio in diets was often missing.

In addition, information was often incomplete or inaccurate on other aspects of the experiments, including details of the method of feeding, the number of times feed was offered each day, and of genotype, sex and stage of growth of the lambs. In some cases the imprecision about weight and age at weaning or slaughter of the lambs also raised difficulties.

4.2. Validity of the data base contents

When available or reliable information was lacking in the literature analysed, some arbitrary choices were made to analyse the data and may have introduced a bias or increased residual error in the statistical models. These arbitrary choices particularly concerned the estimation of the nutritive values.
and the chemical compositions of roughage and concentrate feeds using the tables of INRA (Andrieu et al., 1989). When the diet contained no hay, the level of straw intake could be estimated when it was distributed in a trough, but was not taken into account when no description about straw distribution was found. Consequently, some diets may have been falsely identified as roughage and concentrate or concentrate alone.

Percentages of the fatty acids studied depended on the procedures used in the extraction and esterification of lipid samples, and identification and quantification of the melting point of each peak separated by gas–liquid chromatography. The values expressed in moles were corrected to percentages by weight, but authors generally gave no information on the threshold level for quantification and the fatty acids that were included in the total percentage.

These methodological criteria particularly influenced unsaturated, odd-numbered and branched-chain fatty acid percentages (Beriain et al., 2000a). A bias in the interpretation of the results may have occurred because of the differences in the number of observations for different predictive variables. For example, with castrated males there was very limited nutritional information and a tendency for the lambs to be slaughtered later than either entire males or females.

4.3. General characteristics of fat deposits

The differences in compositions between tissues and between sampling sites observed in this study, irrespective of physiological, dietary, climatic and management conditions, reinforced well established results. Generally, adipose deposits were characterised by a saturation index related with the location of the tissue, and by low melting points in tissues more exposed to environmental temperatures (Cramer and Marchello, 1964; L’Estrange and Mulvihill, 1975; Bas et al., 1987). For example, SC showed a decrease in saturation between the back which is most exposed to outside temperatures, and the dock which is in turn less saturated than the inguinal site.

In SC, our results indicate that percentages of even-numbered saturated fatty acids were associated with that of \( C_{18:0} \) and were opposed to those of \( C_{17:0} \) and \( C_{18:1} \), and that the \( C_{18:2} \) percentage was opposed to that of \( C_{18:1} \). It is already known that unsaturated fatty acids \( C_{18:1} \), \( C_{18:2} \), and \( C_{18:3} \) and odd-numbered fatty acids such as \( C_{17:0} \) largely contribute to lower fat melting points. When the availability of polyunsaturated fatty acids is high, there may be a substitution by a decrease in \( C_{18:1} \) content in subcutaneous adipose tissues probably by the antagonist action on microsomal desaturases. Moreover, an increase in odd-numbered fatty acid percentages, often associated with an increase in the percentages of branched-chain fatty acids resulting from a de novo synthesis from propionate (Garton et al., 1972b), cause a decrease in the percentage of the even-numbered saturated fatty acids with highest melting points.

In PR, the negative correlation between PUFA and long-chain saturated fatty acid percentages indicate an antagonist action of PUFA, when available in relatively large amounts, on the storage of saturated fatty acids. As the activity of desaturase may be lower in PR than in SC (Whale and Garton, 1972) the synthesis of \( C_{18:1} \) may depend on available amounts of \( C_{14:0} \).

In MU lipids, which generally contain more than 50% of phospholipids, the fatty acid composition play an important part in the fluidity of membranes. In MU, variations in the percentages of \( C_{18:2} \) and \( C_{17:0} \) seem to be opposed to that of \( C_{18:0} \), \( C_{18:1} \), and \( C_{18:3} \). Moreover, the percentages of \( C_{18:0} \) and \( C_{18:2} \) seemed to be modulated by those of shorter-chain, even-numbered saturated fatty acids: \( C_{14:0} \) and \( C_{16:0} \).

Although melting point values vary widely with the methodology used (Vimini et al., 1984), variations in Softness Indexes may be closely linked to fatty acid composition. The causes of the lowering of melting points are numerous. Some authors attribute an essential part to increases in odd-numbered and branched-chain fatty acids (Garton et al., 1972a; Bas et al., 1980, 1998; Miller et al., 1980) while under other conditions monoenic (L’Estrange and Mulvihill, 1975; Gibney and L’Estrange, 1975) and dienic fatty acids (Gibney and L’Estrange, 1975) seem to be responsible for the lowering of fat melting points. The latter study indicated that whatever experimental conditions, the lowering of fat melting points was best explained by a fall in \( C_{18:0} \) percentage, and not by a fall in total saturated fatty acids, and by an increase in \( C_{18:2} \) percentage. Other
factors, like the variations of the percentages of position isomers and more markedly geometric isomers of fatty acids, probably have a significant influence on melting point, but isomers of fatty acids have been very seldom studied in the literature analysed in this data base.

4.4. Influence of feeding on the fatty acid composition of tissues

In young lambs fed milk rich in lipids, the profile of fatty acids of fat deposits and muscles largely reflected the dietary fatty acid profile, but the composition of the various tissues revealed some differences in relation with their functional specificity. Thus, this study clarified the influence of both amount and nature of dietary fat on concomitant variations of fatty acid composition in each adipose tissues and muscle. The influence of dietary fatty acids on body composition was particularly marked at this stage of growth because of the high lipid accretion almost exclusively from circulating fatty acids. However, the results of this study suggested that C_{12:0}, C_{14:0}, and C_{16:0}, when available at a high level, may be successively elongated to stearic acid and converted into monoeneic fatty acids with 16 or 18 atoms of carbon by desaturation. On the other hand, long-chain fatty acids did not appear to be converted into smaller-chain fatty acids. When the diet contained very small amounts of PUFA, the PUFA percentage was often high in adipose tissues and even higher in muscles, probably because of their higher coefficients of digestibility, as compared to other fatty acids (Walker and Stokes, 1970), and also to their low degradation in tissues because of their preferential position on C2 of triacylglycerols (Hawke et al., 1977).

After weaning, the differences of composition between tissues appeared more pronounced than before weaning. Beside composition specificities of adipose tissues, in relation with their functions and locations, fatty acid composition of lamb tissues after weaning depended on a larger number of factors such as the presence of some fatty acids laid down before weaning in adipose tissues containing more and more newly deposited fatty acids. This effect depends on age and weight at weaning, on the length of the post-weaning period (Bas, 1993), the relative prevalence of one of the two processes of lipid storage which differ from one tissue to another, namely the de novo synthesis or from circulating fatty acids (Payne and Masters, 1971; Ingle et al., 1972a,b; Haugebak et al., 1974; Vezinhet et al., 1983). This is also affected by other factors, including age, sex, level of fattening.

Dietary lipid of energy and protein sources in the data base, except fish meal, contained between 75 and 90% of C_{18} fatty acids, mainly PUFA (dienic fatty acids in cereals, soybean meal, cotton seeds or cotton meal and trienic fatty acids in alfalfa and grass). These dietary lipids are hydrolysed in the rumen and the PUFA released changed into cis or trans monoeneic fatty acids, mostly C_{18:0}. The degree of hydrolysis of these PUFA varies from 70 to 100% when they are not protected (Doreau and Ferlay, 1994).

With diets containing beet pulp or fish meal as main energy or nitrogen sources, lipid compositions of the different fat deposits were similar and characterised by low levels of C_{18:0}, C_{18:2}, C_{18:3} and total saturated fatty acids, and by a high level of C_{18:1}. This may be the result of low C_{18} fatty acid uptake into tissues resulting from the low contents of these fatty acids in these two ingredients. The storage of these acids from fish meal may also be reduced by inhibition of both fatty acid uptake and rumen microbial synthesis of fatty acids in the presence of PUFA with chains longer than 20 carbon atoms (Storry et al., 1974). Long-chain PUFA from fish meal seems to be hydrogenated in the rumen to a lesser extent than C_{18} fatty acids and seems to be neither reduced into shorter fatty acids nor deposited in the triacylglycerols of adipose tissues and muscles although they may be stored as phospholipids (Ashes et al., 1992).

Diets in which maize or cotton meal were the main energy or nitrogen sources led to fat deposits richer in C_{18} acids, mainly due to the linoleic acid content of these ingredients. This high percentage of linoleic acid in tissues from lambs fed diets rich in cotton meal, which has similarities with studies on cow milk (Wu et al., 1994), may be the result of the high levels of linoleic acid supplied with cotton seeds or largely unextracted meal, in view of the increased stearic acid and decreased linolenic acid.
percentages in tissues of these lambs. On the other hand, the high levels of linoleic and linolenic acids in tissues and unchanged percentage of stearic acid, which is terminal product of PUFA hydrogenation seems to indicate that PUFA from maize are less easily hydrogenated than PUFA from other cereals or meals. This resistance of maize lipids to hydrogenation may result from the lower ruminal degradability of maize protein and starch than that of other cereals (Nocek and Tamminga, 1991). Maize may lead to relatively high levels of odd-numbered fatty acids as the synthesis of fatty acids by rumen microorganisms is known to be at least twice as high with maize than with barley diets (Brumby et al., 1979), and as lipids synthesised by microorganisms are relatively rich in odd-numbered fatty acids (Ifkovits and Ragheb, 1968; Viviani, 1970; Bas et al., 2000).

The C₁₈ PUFA from wheat and barley appears to be more hydrolysed and hydrogenated in the rumen than that from maize. Wheat tended to produce a higher percentage of stearic acid and a lower percentage of oleic acid in tissues than barley as a result of its higher levels of C₁₈ PUFA and lower levels in oleic acid. But, with wheat and barley, the odd-numbered and branched chain fatty acid percentages were often increased in SC with a concomitant reduction in stearic acid. These fatty acids could result from de novo synthesis from propionate as the high content of rapidly rumen-degradable starch in wheat and barley decreases ruminal pH and increases production of propionate.

The particularly high percentage of linolenic acid in adipose tissues and muscles with a grass-based diet (2–3% fat/DM) may result from the high linolenic acid content in grass (>50% of total fatty acids), a part of which would resist to hydrogenation because of the high level of linoleic acid itself. There may also be considerable protection against hydrogenation of intracellular galactosyglycerols in the rumen when the feed was not in crushed or ground forms (Ben Salem et al., 1993). Similarly, the relatively high percentage of linolenic acid found in lambs receiving diets rich in soybean meal or alfalfa meal, although lower than with grass-based diets, could be linked to the high linolenic content in these meals, 7–10%, and 30–35%, respectively.

5. Conclusion

In spite of the difficulties met in comparing fatty acid compositions obtained with different procedures of quantification, and a lack of information concerning management conditions and diet characteristics, the results obtained from this review of the literature nevertheless contribute to a better appreciation of the magnitude of feed effects on the fatty acid composition of lamb tissues. All raw materials contained in diets may have an influence on the fatty acid composition of lamb tissues by both amount and composition of lipids in each ingredient, in relation with nature, fibrosity and chemical composition of the total diet. This study, which consisted in making and analysing a data base, gives an objective view of the effects of dietary ingredients on the lipid composition of tissues and quality of lamb carcasses. Better control of the lipid composition of lamb carcasses would result from carefully considering these dietary factors when managing lambs and designing their diets.

6. For further reading

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et al., 1972b; Jacobs et al., 1973; Jenkins et al., 1994; Johnson et al., 1988; Kemp et al., 1981; L’Estrange and Hanrahan, 1980; L’Estrange, 1977; L’Estrange, 1979; Leat et al., 1997; Leth et al., 1998; Lough et al., 1992; Manfredini and Cavana, 1979; Marinova et al., 1992; Marinucci et al., 1998; Matthies et al., 1998; Matthies et al., 1996; Miller and Rice, 1967a; Miller et al., 1967b; Molénaër and Thérèzé, 1973; Murphy and L’Estrange, 1977; Muscio et al., 1978; Muscio et al., 1980; Normand et al., 2000; Nürnberg et al., 1996; Oršković et al., 1975; Pearce et al., 1974; Petit et al., 1997; Purchas et al., 1979; Quackebeke et al., 1978; Ray et al., 1975; Rule et al., 1991; Safari et al., 1988; Sañudo et al., 1998; Sarti et al., 1993; Shindarska et al., 1992; Sinnett-Smith et al., 1989; Solomon et al., 1992; Solomon et al., 1990; Solomon et al., 1991; Spillane and Walker, 1970; Takahashi and Ota, 1985; Thérèzé et al., 1976; Tichenor et al., 1970; Vesely, 1973; Vipond et al., 1995; Webb et al., 1994a; Webb et al., 1994b; Webb and Casey, 1995; Wu and Savell, 1992; Ziegler et al., 1967; Zmala’carregui Rodríguez and Burgos Gonzalez, 1975; Zygoniannis et al., 1985.

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