Effects of Dietary Canola Seed and Soy Lecithin in High-Forage Diets on Cholesterol Content and Fatty Acid Composition of Carcass Tissues of Growing Ram Lambs

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ABSTRACT: Phospholipids (soy lecithin) are important in the emulsification of lipids and may escape the rumen and influence the absorption of fatty acids in the small intestine. Our objectives were to determine the influence of dietary canola seed (high in unsaturated fatty acids) and soy lecithin in high-forage diets on total lipid content, cholesterol content, and fatty acid composition of carcass tissues. Forty-three Hampshire or Suffolk-sired ram lambs were weaned at 60 d of age (average 23.6 kg of BW) and assigned to a 2 x 2 factorial arrangement of treatments consisting of 1) basal diet (control = BAS), 2) BAS with 6% whole canola seed (CS), 3) BAS with 4.9% deoiled soy lecithin (SL), and 4) BAS with 6% CS and 4.8% SL (CSSL). The BAS diet consisted of 70% forage and 30% concentrate and contained 15% CP and 2.2 Mcal of ME/kg. Lambs were individually fed and given ad libitum access to feed to an average final BW of 52.1 kg. Longissimus muscle (LM) from the left side of each carcass posterior to the 13th rib (12 to 15 cm in length) was excised and the lean (LM) and corresponding subcutaneous (s.c.) adipose tissue were separated, frozen, and later used for lipid analysis by gas-liquid chromatography. In lean tissue, feeding lambs CS reduced (P < .01) the proportion of total polyunsaturated fatty acids (PUFA) and feeding SL increased (P < .01) the proportion of total PUFA. In s.c. adipose tissue, lambs fed CS had lower (P < .01) saturated fatty acids (SFA) and lambs fed SL had increased (P < .03) PUFA. Feeding CSSL had little effect on fatty acid composition of carcass tissues compared with feeding CS and SL alone. Reducing SFA and(or) increasing PUFA in carcass tissues represents a favorable change in regard to current human dietary guidelines.

Key Words: Lambs, Rapeseed, Phospholipids, Fatty Acids, Cholesterol

Introduction

Currently, health professionals are recommending diets low in saturated fats, cholesterol, and energy to reduce the risk of chronic atherosclerosis. With the population of the United States becoming more health-conscious, there has been a decrease in the consumption of animal fat and an increase in the consumption of vegetable fat (NRC, 1988). Therefore, animal scientists and the food industry need to devise strategies so livestock producers can produce red meat products that meet current human dietary guidelines.

The addition of canola seed to the diet of beef steers increased the quantity of polyunsaturated fatty acids (PUFA) and decreased the amount of palmitic acid in adipose tissue (Rule et al., 1989).
This effect was likely due to the unsaturated fatty acids in canola seed escaping ruminal fermentation. Phospholipids have surface active properties, are important in the emulsification of lipids, and may influence the absorption of fatty acids in the small intestine (Jenkins et al., 1989; Jenkins, 1990). Previously, we reported the effects of feeding 6% canola seed in conjunction with 4.8% soy lecithin in high-forage diets on performance, serum lipids, and carcass characteristics of growing ram lambs (Lough et al., 1991). This paper reports the effects of dietary canola seed and soy lecithin on total lipid content, cholesterol content, and fatty acid composition of carcass tissues of those same growing ram lambs fed a high-forage diet.

**Materials and Methods**

**Animals and Diets.** Forty-three Hampshire or Suffolk-sired ram lambs were assigned to the following treatments: 1) basal diet (control = BAS), 2) BAS + 6% whole canola seed (CS), 3) BAS + 4.9% deoiled soy lecithin (SL), and 4) BAS + 6% whole canola seed and 4.8% deoiled soy lecithin (CSSL). All diets were composed to 70% forage and 30% concentrate and the lambs were individually fed and given ad libitum access to feed. The BAS diet contained 15% CP and 2.2 Mcal of ME/kg. Diet composition and management of the lambs were previously described by Lough et al. (1991). The lambs were started on trial at approximately 60 d of age (average 23.6 kg BW) and were slaughtered according to USDA humane slaughter practices at an average final BW of 52.1 kg.

**Isolation of Lipids.** Loin sections were removed from each carcass at 24 h postmortem. The longissimus muscle (LM) from the left side posterior to the 13th rib (12 to 15 cm in length) was excised and the lean (LM) and corresponding s.c. adipose tissue were separated, frozen (−20°C), and later used for lipid analysis. An Omni-Mixer homogenizer and the Folch et al. (1957) procedure were employed to obtain lipid extracts of each sample. Lean and adipose samples were homogenized and extracted three times with a 2:1 chloroform:methanol mixture (vol/vol). A .58% aqueous NaCl solution was added to the homogenate, causing the organic layer (containing lipid) to separate from the methanol-water phase. In the aforementioned extract, chloroform, methanol, and water (.58% NaCl) including water contributed from the tissue were in the proportions 8:4:3 by volume. Aliquots of the lipid extract were transferred to screw-cap test tubes for subsequent fatty acid and cholesterol analyses.

**Fatty Acid Analysis.** Fatty acids were converted into methyl ester derivatives before GLC analysis. Methyl heneicosanoate (C21:0; 3.70 mg/mL) served as the internal standard. Along with each set of samples esterified, a triglyceride standard (tripalmitin; 3.76 mg/mL) and control sample were included to check on the consistency and accuracy of the results. The control sample was a lipid extract from a randomly selected loin sample analyzed in the study. Methylation and preparation of samples for GLC analysis were described previously (Solomon et al., 1990).

Separation of methyl esters of fatty acids was performed on a gas chromatograph (Model 5880A, Hewlett-Packard, Avondale, PA) designed to accommodate a capillary column. The gas chromatographic technique of Slover and Lanza (1979) was followed to quantitify fatty acids resolved on a 30-m SP 2330 Fused Silica capillary column (Supelco, Bellefonte, PA). Helium served as the carrier gas and makeup gas (column flow rate = .8 mL/min and makeup flow rate = 30 mL/min). Temperatures of the injector, oven, and detector were 200, 170, and 200°C, respectively.

**Cholesterol Analysis.** Cholesterol was converted to a trimethylsilyl ether derivative, with stigmasterol (.39 mg/mL) serving as the internal standard. The derivatizing procedure and sample preparation were described previously (Solomon et al., 1990).

Analysis of the cholesterol was performed on a gas chromatograph (Model 5880A, Hewlett-Packard) designed to accommodate a packed column. A 1.8-m x 4-mm glass column packed with 3% OV-17 on Gas Chrom Q (100/120) (Alltech Associates, Deerfield, IL) was used to resolve the cholesterol and stigmasterol peaks. Helium served as the carrier gas and column flow rate was 50 mL/min. Temperatures of the injector, oven, and detector were 300, 270, and 300°C, respectively.

**Data Analysis.** Data were analyzed by the GLM procedure of SAS (1985) to determine the significance of variation among diets. For all data, the statistical model included CS, SL, and the CS x SL interaction.

**Results and Discussion**

**Lean Tissue**

Total lipid content, cholesterol content, and fatty acid composition of LM of growing ram lambs fed the experimental diets are presented in Table 1. Total lipid content of LM was not different among treatments; however, lambs fed SL tended (P < .09) to have more i.m. lipid, which may be due to the 19% greater ME intake (Lough et al., 1991). Cholesterol content of LM was not different among treatments. The average cholesterol content of LM was 62.4 mg/100 g of tissue; this is comparable to the 64.2 mg/100 g of tissue for ram lambs fed a
DIETARY CANOLA SEED AND SOY LECITHIN

Table 1. Effects of dietary canola seed and soy lecithin fed to growing ram lambs on total lipid content, cholesterol content, and fatty acid composition of longissimus muscle

<table>
<thead>
<tr>
<th>Item</th>
<th>BAS</th>
<th>CS</th>
<th>SL</th>
<th>CSSL</th>
<th>SEM</th>
<th>Probability of significance</th>
</tr>
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<tbody>
<tr>
<td>Dieta</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total lipid, g/100 g</td>
<td>3.18</td>
<td>3.17</td>
<td>3.57</td>
<td>3.71</td>
<td>.27</td>
<td>.81</td>
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<tr>
<td>Cholesterol, mg/100 g</td>
<td>61.2</td>
<td>62.4</td>
<td>62.2</td>
<td>83.6</td>
<td>.94</td>
<td>.16</td>
</tr>
<tr>
<td>Fatty acid, %b</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Myristic</td>
<td>1.77</td>
<td>1.58</td>
<td>1.44</td>
<td>1.53</td>
<td>.12</td>
<td>.65</td>
</tr>
<tr>
<td>Palmitic</td>
<td>18.67</td>
<td>16.64</td>
<td>16.79</td>
<td>16.35</td>
<td>.51</td>
<td>.52</td>
</tr>
<tr>
<td>Palmitoleic</td>
<td>1.59</td>
<td>1.36</td>
<td>1.22</td>
<td>1.40</td>
<td>.11</td>
<td>.83</td>
</tr>
<tr>
<td>Margaric</td>
<td>.86</td>
<td>.71</td>
<td>.80</td>
<td>.65</td>
<td>.05</td>
<td>.01</td>
</tr>
<tr>
<td>Stearic</td>
<td>13.83</td>
<td>13.44</td>
<td>14.18</td>
<td>14.64</td>
<td>.37</td>
<td>.52</td>
</tr>
<tr>
<td>Oleic</td>
<td>30.66</td>
<td>30.19</td>
<td>29.05</td>
<td>31.80</td>
<td>1.03</td>
<td>.32</td>
</tr>
<tr>
<td>Linoleic</td>
<td>4.89</td>
<td>4.13</td>
<td>6.28</td>
<td>5.08</td>
<td>.25</td>
<td>.01</td>
</tr>
<tr>
<td>Linolenic</td>
<td>.78</td>
<td>.72</td>
<td>.75</td>
<td>.60</td>
<td>.09</td>
<td>.05</td>
</tr>
<tr>
<td>Arachidonic</td>
<td>1.35</td>
<td>1.13</td>
<td>1.41</td>
<td>1.22</td>
<td>.10</td>
<td>.05</td>
</tr>
<tr>
<td>UNID&lt;sup&gt;c&lt;/sup&gt;</td>
<td>2.29</td>
<td>2.17</td>
<td>2.19</td>
<td>2.09</td>
<td>.15</td>
<td>.46</td>
</tr>
<tr>
<td>Total SFA&lt;sup&gt;d&lt;/sup&gt;</td>
<td>34.26</td>
<td>31.98</td>
<td>32.41</td>
<td>32.71</td>
<td>.72</td>
<td>.12</td>
</tr>
<tr>
<td>Total MUFA&lt;sup&gt;d&lt;/sup&gt;</td>
<td>32.45</td>
<td>31.55</td>
<td>30.27</td>
<td>33.20</td>
<td>1.09</td>
<td>.36</td>
</tr>
<tr>
<td>Total PUFA&lt;sup&gt;d&lt;/sup&gt;</td>
<td>7.03</td>
<td>5.67</td>
<td>8.44</td>
<td>6.89</td>
<td>.38</td>
<td>.01</td>
</tr>
<tr>
<td>P:S&lt;sup&gt;e&lt;/sup&gt;</td>
<td>.21</td>
<td>.19</td>
<td>.28</td>
<td>.21</td>
<td>.01</td>
<td>.02</td>
</tr>
</tbody>
</table>

a BAS = control (n = 11 ram lambs); CS = whole canola seed (n = 11 ram lambs); SL = deoiled soy lecithin (n = 10 ram lambs) and CSSL = whole canola seed + deoiled soy lecithin (n = 11 ram lambs).

b Percentage of total lipid.

c UNID = unidentified fatty acids.

d SFA = saturated fatty acids; MUFA = monounsaturated fatty acids; PUFA = polyunsaturated fatty acids.

e Ratio of polyunsaturated to saturated fatty acids.

High-forage diet reported by Solomon et al. (1990). The cholesterol content of LM of ram lambs fed a whole rapeseed-soybean meal diet was 74.7 mg/100 g (Solomon et al., 1991). Although the role of dietary cholesterol as a contributor to plasma cholesterol is questionable (Food and Nutrition Board, 1980), the general recommendation is to limit intake to 100 mg/1,000 kcal, not to exceed 300 mg/d (American Heart Association, 1986). The cholesterol content of lamb meat is consistent with this recommendation and compares favorably with poultry, fish, and beef (NRC, 1988).

Oleic acid (C18:1) was the most abundant fatty acid in the lipid fraction of LM, and there were no differences among treatments. Also, St. John et al. (1987) found no differences in oleic acid content of LM and semimembranosus muscle from steers fed a diet containing 20% CS. Monounsaturated fatty acids (MUFA), such as oleic acid, have been reported to be hypolipidemic, reducing both cholesterol and LDL triglycerides (Grundy, 1986). Mattson and Grundy (1983) demonstrated that oleic acid has the ability to reduce LDL cholesterol. Palmitic acid (C16:0) was the second most abundant fatty acid in the total lipid fraction of LM. Feeding CS and SL significantly reduced the palmitic acid content of LM. The CSSL treatment reduced the palmitic acid content of LM by 12% compared with BAS. The lambs fed the CS, SL, and CSSL diets had higher lipid intakes because these diets contained more lipid than did the BAS diet and DMI was not affected by treatment (Lough et al., 1991). Yang et al. (1978) reported decreased in vitro lipogenesis from acetate and glucose in adipose tissue of steers and lambs fed added dietary fat. Similar effects may be expected in lean tissue, thereby reducing the de novo synthesis of palmitic acid. St. John et al. (1987) found no differences between the palmitic acid content of LM and semimembranosus muscle from steers fed a 20% CS high-concentrate diet compared to that from steers fed a control diet. Solomon et al. (1991) reduced the palmitic acid content of LM by 9% by feeding a whole rapeseed-soybean meal or soybean meal-supplemented diet compared with a rapeseed meal-supplemented diet. Palmitic acid has been reported to be hyperlipidemic and thus may increase serum cholesterol levels (Keys et al., 1965). Myristic acid (C14:0), which also has been reported to be hyperlipidemic (Keys et al., 1965), represented only 1.58% of the lipid fraction of LM and was not different among treatments.

Stearic acid (C18:0) was the third most abundant fatty acid. Feeding SL increased (P < 0.03) the stearic acid content of LM, but CS had no effect. St. John et al. (1987) reported no differences in the stearic acid content of muscle tissue from steers fed a 20% CS diet. Similarly, Busboom et al. (1991) reported no effect of 20% whole or ground canola on stearic acid content of LM from finishing pigs. Conversely, Solomon et al. (1991) reported an increase in stearic acid content of LM of ram lambs fed a whole rapeseed-soybean meal diet.
compared with a rapeseed meal diet. Bananome and Grundy (1988) recently demonstrated that a diet high in stearic acid did not elevate plasma levels of LDL cholesterol, perhaps because it is poorly digested and can be easily desaturated to oleic acid. Linoleic acid (C18:2) was significantly increased by feeding SL and significantly decreased by feeding CS. The increase in linoleic acid may be due to an emulsification effect of SL. St. John et al. (1987) and Solomon et al. (1991) reported no effect of a 20% CS or a whole rapeseed-soybean meal supplemented diet, respectively, on linoleic fatty acid content of muscle tissue. Feeding CS also reduced (P < .05) the linolenic acid (C18:3), arachidonic acid (C20:4), and margaric acid (C17:0) content of LM. Treatments had no effect on the palmitoleic acid (C16:1) and unidentified fatty acid (UNID) content of LM. Although it was not analyzed statistically, lambs fed CS had LM with detectable concentrations of arachidic acid (C20:0), behenic acid (C22:0), eicosenoic (C20:1), and erucic acid (C22:1) (data not presented), and these fatty acids made up 3.7% of fatty acids for CS and 3.0% of the fatty acids for CSSL. The addition of these fatty acids to the UNID, total saturated fatty acids (SFA), total MUFA, and total PUFA resulted in similar proportions of total fatty acids for each treatment (average = 75.6% of total lipid). In LM of lambs fed CS, the presence of arachidic, behenic, eicosenoic, and erucic acids with a decrease in linoleic and linolenic acids was unexpected. Linoleic and linolenic acids may be metabolized in the rumen; however, no changes in either stearic or oleic acids were observed in LM of lambs fed CS. Feeding oilseeds high in unsaturated fatty acids is an effective way of modifying the fatty acid composition of carcass tissues to produce a more healthful product for human consumption.

Treatments had no effect on total SFA in LM. Canola seed decreased the SFA content on the BAS diet but caused a slight increase in the SFA content on the SL diet, resulting in a significant CS x SL interaction. Solomon et al. (1991) and St. John et al. (1987) found no differences in the SFA content of LM from ram lambs fed whole rapeseed-soybean meal diet and LM of cattle fed 20% rapeseed, respectively. Total MUFA was not affected by treatments. Solomon et al. (1991) reported no differences in the MUFA content of LM from ram lambs fed whole rapeseed-soybean meal diet. Feeding CS significantly reduced the PUFA in LM because CS reduced linoleic, linolenic, and arachidonic acids. The linoleic and linolenic acid content of LM should have increased by feeding CS because CS contains linoleic and linolenic acid (St. John et al., 1987). The linolenic acid content of LM of finishing pigs was increased by feeding both intact and ground canola (Busboom et al., 1991). Feeding SL increased (P < .01) PUFA in LM, which was due to an increase in linoleic acid content by feeding SL. Polyunsaturated:saturated (P:S) ratio was reduced (P < .02) by feeding CS and increased (P < .01) by feeding SL. The P:S ratio, according to some health specialists, may be an important factor in the control of serum cholesterol for individuals in high-risk categories for coronary heart disease (Food and Nutrition Board, 1980). Therefore, the selection of foods with the proper P:S ratio by these high-risk individuals may be important in the control of their serum cholesterol.

Subcutaneous Adipose Tissue

Total lipid content, cholesterol content, and fatty acid composition of s.c. adipose tissue of growing ram lambs fed the experimental diets are presented in Table 2. Feeding CS and SL significantly increased the total lipid content of s.c. adipose tissue, and the greater ME intake by the lambs fed SL may explain the SL effect (Lough et al., 1991). Solomon et al. (1991) reported no effect of a whole rapeseed-soybean meal diet on the total lipid content of s.c. adipose tissue. The total lipid content of s.c. adipose tissue for CSSL was increased by 13% compared with BAS. The feeding of SL significantly reduced the cholesterol content of s.c. adipose tissue. Solomon et al. (unpublished data) noted a decrease in cholesterol content of s.c. adipose tissue of ram and ewe lambs fed a diet with 10.8% palm oil. Feeding CS tended (P < .08) to increase the cholesterol content of s.c. adipose tissue. Solomon et al. (1991) reported an increase in cholesterol content of s.c. adipose tissue associated with LM from ram lambs by feeding whole rapeseed-soybean meal diet compared with rapeseed meal. Diersen-Schade et al. (1986) found higher cholesterol concentrations in s.c. and perirenal adipose tissue of young pigs fed a high-PUFA diet.

Oleic acid was the most abundant fatty acid present in s.c. adipose tissue. A significant CS x SL interaction was noted for oleic acid, of which the biological significance is not known. Soy lecithin may have caused an increase in absorption of oleic acid on the CS diet but not on the BAS diet. St. John et al. (1987) reported no effect of a 20% rapeseed diet on oleic acid composition of adipose tissue in steers. Likewise, Rule et al. (1989) found no differences in oleic acid content of s.c. adipose tissue of steers fed ground canola seed. However, Busboom et al. (1991) reported an increase in oleic acid content of s.c. adipose tissue of swine fed ground canola. Stearic acid was significantly increased in s.c. adipose tissue by feeding SL. This should not pose a health risk because stearic acid did not elevate plasma levels of LDL cholesterol in the experiments of Bonanome and Grundy (1988).
In growing ram lambs, Solomon et al. (1991) reported an increase in the stearic acid content of s.c. adipose tissue associated with LM by feeding a whole rapeseed-soybean meal-supplemented diet. Likewise, Rule et al. (1989) increased the stearic acid content of s.c. adipose tissue of steers fed a CS-supplemented diet.

Palmitic acid was the third most abundant fatty acid present in s.c. adipose tissue. As with oleic acid, a significant CS × SL interaction was present, of which the biological significance is unknown. Solomon et al. (1991) reported no effect of a diet containing whole rapeseed-soybean meal on palmitic acid content of s.c. adipose tissue corresponding with LM of growing rams. Others have reduced palmitic acid content of s.c. adipose of steers by feeding CS (St. John et al., 1987; Rule et al., 1989). Busboom et al. (1991) reduced the palmitic acid content of s.c. adipose tissue of swine fed ground canola, but there was no effect with feeding intact canola. Myristic acid, which is also considered to be hyperlipidemic (Keys et al., 1965), was reduced \( P < .01 \) by feeding SL. Reducing the myristic and palmitic acids in adipose tissue is a positive step in producing lamb that meets current human dietary guidelines.

Feeding SL increased \( P < .01 \) and feeding CS decreased \( P < .01 \) the linoleic acid content of s.c. adipose tissue, which was the same response seen in LM. The linoleic acid content of s.c. adipose tissue of swine was increased by feeding intact and ground canola (Busboom et al., 1991). Linolenic acid was significantly decreased by feeding SL and significantly decreased by feeding CS. Linolenic acid was reduced by 42% on CSSL treatment compared with BAS and the effects of CS and SL seem to be additive (no CS × SL interaction). Others have increased the linolenic acid content of s.c. adipose issue in swine (Busboom et al., 1991) and cattle (Rule et al., 1989) by feeding canola. Perhaps greater quantities (\( > 6\% \)) of whole canola seed need to be included in the diet to increase the amounts of linoleic and linolenic acids found in s.c. adipose tissue of growing ruminants. Pentadecylic acid \( (C15:0) \) was reduced by feeding CS; however, it made up < 1% of the total lipid. A significant CS × SL interaction was detected in the palmitoleic acid data, which may have no nutritional significance for humans because palmitoleic acid made up approximately 2% of the total lipid. Margaric acid was reduced \( P < .01 \) by feeding SL and CSSL. The CSSL treatment reduced the margaric acid content by 34% compared with BAS and the effects of CS and SL were additive (no CS × SL interaction). Feeding SL significantly increased and feeding CS significantly decreased the UNID in s.c. adipose tissue. As with LM, the feeding of CS resulted in detectable quantities of arachidic, behenic, eicosenoic, and erucic acids deposited in s.c. adipose tissue (data not presented), and these fatty acids made up 9.8% of fatty acids for CSSL and 6.3% of the fatty acids for CSSL. The addition of these fatty acids to the UNID, total SFA, total MUFA, and total PUFA.
resulted in similar proportions of total fatty acids for each treatment (average = 95.7% of total lipid). As with LM of lambs fed CS, the presence of arachidic, behenic, eicosanoic, and erucic acids with a decrease in linoleic and linolenic acids of s.c. adipose tissue was unexpected.

Total SFA were reduced by feeding CS and the reduction in palmitic acid was mostly responsible for this effect. Solomon et al. (1991) found that a soybean meal-supplemented diet lowered total SFA in s.c. adipose tissue compared with a whole rapeseed-soybean meal-supplemented diet. No differences in total SFA in adipose tissue were found between a control and a 20% rapeseed-supplemented diet fed to steers (St. John et al., 1987). A significant CS × SL interaction was present for total MUFA because palmitoleic and oleic acids had significant CS × SL interactions. Total PUFA were reduced (P < .01) by feeding CS, and this was due to the reduction in linoleic and linolenic acids. Also, total PUFA were increased (P < .03) by feeding SL, and this effect was due to the increase in linoleic acid in s.c. adipose tissue. The P:S ratio was reduced (P < .01) by feeding CS, and the reduction in total PUFA by feeding CS may account for the smaller P:S ratio.

Implications

Feeding canola seed reduced total saturated fatty acids in subcutaneous adipose tissue but not in longissimus muscle. Feeding soy lecithin increased polyunsaturated fatty acids in longissimus muscle and subcutaneous adipose tissue; however, more subcutaneous adipose tissue was present and it had a higher lipid content. Reducing the saturated fatty acids and increasing the polyunsaturated fatty acids in carcasses of meat animals represents a favorable change in regard to current human dietary guidelines. The addition of oilseeds high in unsaturated fatty acids to high-forage diets of growing ruminants may have some beneficial effect in producing a desirable product for consumption by health-conscious individuals.

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