Effect of dietary vegetable oils on the fatty acid profile of plasma lipoproteins in dairy cows

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ABSTRACT

The aim of this study was to elucidate the effect of dietary supplementation of soybean oil (SO) and hydrogenated palm oil (HPO) on the transport of fatty acids (FA) within plasma lipoproteins in lactating and non-lactating cows. Three lactating and three non-lactating Holstein cows were used in two different 3 × 3 Latin square experiments that included three periods of 21 d. Dietary treatments for lactating cows consisted of a basal diet (control; no fat supplement) and fat-supplemented diets containing SO (500 g/d per cow) or HPO (500 g/d per cow). For non-lactating cows, dietary treatments consisted of a basal diet (control; no fat supplement) and fat-supplemented diets containing SO (170 g/d per cow) or HPO (170 g/d per cow). Compared with the control and SO diet, HPO addition increased (p < 0.05) the concentration of C16:0, C18:0, C18:2cis-9,12, C18:3cis-9,12,15 and total saturated and polyunsaturated FA in the plasma of lactating cows. In non-lactating cows, the SO addition increased the plasma concentration of C18:1trans-11. In lactating cows, concentrations of C16:0, C18:0 and total saturated FA were increased (p < 0.05) by HPO addition in the high-density lipoprotein (HDL). Total saturated FA were increased (p < 0.05) by HPO in very-low-density lipoprotein (VLDL). In non-lactating cows, the concentration of C18:0 was increased (p < 0.05) by HPO in HDL, whereas C18:1trans-11 was increased (p < 0.05) by SO in the low-density lipoprotein. Overall, it was found that distribution and transport of FA within the bovine plasma lipoproteins may be influenced by chain length and degree of unsaturation of dietary lipids. Also, the distribution of individual FA isomers such as C18:1trans-11 and C18:2cis-9,trans-11 may vary depending on the physiological state of the cow (lactating or non-lactating), and are increased in plasma (lactating cows) and the HDL (non-lactating cows) when cows are fed SO.

1. Introduction

Supplementing dairy cow diets with soybean oil (SO) can increase milk yield with no detrimental effect on milk fat content (Bu et al. 2007). Milk bioactive fatty acids (FA) such as vaccenic acid (C18:1trans-11) can be increased by inclusion of SO into dairy...
cow diets (Allred et al. 2006; Vargas-Bello-Pérez et al. 2015). On the other hand, hydrogenated vegetable oils have been used to increase the energy content of dairy cow diets in confinement (Kargar et al. 2012) and pasture systems (Schroeder et al. 2002) without any effect on milk composition (Vargas-Bello-Pérez et al. 2015).

It is difficult to increase polyunsaturated FA (PUFA) concentrations in milk, since large amounts of dietary lipid supplements are needed to achieve a meaningful rise in milk concentration of PUFA (Offer et al. 2001). In bovines, the effects of dietary PUFA on lipoprotein metabolism are difficult to define since they depend on the degree of protection against biohydrogenation (Scisłowski et al. 2004a) and the location, orientation and number of double bonds of dietary lipids (Tyburczy et al. 2008). Dietary PUFA can alter lipoproteins, especially the high-density lipoprotein (HDL) fraction, which is the major plasma lipoprotein fraction in bovines (Bauchart 1993). For example, the HDL lipid profile can be modified when dietary PUFA are directly infused into the proximal duodenum (Scisłowski et al. 2004a) or when pre-ruminant calves are supplemented with SO (Leplaix-Charlat et al. 1996) or when dairy cows are fed protected sunflower oil seed (Ashes et al. 1982) or protected soybean (Storry et al. 1980).

Understanding how dietary FA affect lipoprotein metabolism in dairy cows is important because this knowledge could be used to modulate the effect of nutrition on milk fat yield and milk FA quality. Therefore, the aim of this study was to elucidate the effect of dietary FA on the FA profile of plasma lipoproteins when lactating and non-lactating cows are supplemented with polyunsaturated (SO) or saturated [hydrogenated palm oil (HPO)] lipid sources.

2. Materials and methods

2.1. Animals and diets

All animals were handled following approved guidelines of the Animal Care and Use Committee of the Pontificia Universidad Católica de Chile. The study was conducted at the Estación Experimental Pirque (33°38′28″S, 70°34′27″W) of the Pontificia Universidad Católica de Chile. Three lactating cows averaging 169 ± 24 days in milk at the beginning of the study [mean ± standard deviation: 641 ± 111.3 kg body weight (BW)] and three non-lactating non-pregnant Holstein cows (685 ± 84.7 kg BW) were used in two different 3 × 3 Latin square designs with three periods consisting of 21 d. Cows were individually fed a total mixed ration at a fixed rate once daily (09:30 h).

All cows received a basal diet formulated with a 56:44 forage:concentrate ratio, which was fed at rates determined by NRC (2001). Lactating cows received 19.5 kg dry matter (DM) per day of the basal diet to meet the requirements of cows producing 30 l milk per day; non-lactating cows received 10 kg DM per day of the basal diet. Dietary treatments for lactating cows consisted of the basal diet (control; no fat supplement) and fat-supplemented diets containing SO (unrefined oil; 500 g/d per cow) or HPO (500 g/d per cow). For non-lactating cows, the dietary treatments were basal diet (control; no fat supplement), SO (basal diet + 170 g SO/d per cow) or HPO (basal diet + 170 g HPO/d per cow). Amounts of oil fed to animals were based on Vargas-Bello-Pérez et al. (2015). Experimental diets were calculated to be isonitrogenous. Standard procedures (AOAC 2006) were used to determine DM (934.01), Kjeldahl N
Neutral detergent fibre and acid detergent fibre and lignin were determined by methods described by Van Soest et al. (1991). Chemical composition of the diets is shown in Table 1. A mixer wagon was used to mix forage and concentrates. Oils were administrated separately and mixed manually. The most important FA (g per 100 g) in SO were 25 of C18:1 \textit{cis}-9 and 51 of C18:2 \textit{cis}-9,12; whereas HPO contained 47 of C16:0 and 43 of C18:0. Animals were housed in individual stalls (2.4 m × 6 m) and had continuous access to water.

### 2.2 Blood and lipoprotein samples

Blood samples (50 ml/cow) were obtained at 10:00 h via jugular puncture on day 21 of each period before the morning meal. Blood was transferred to tubes containing lithium heparin (BD Vacutainer; Franklin Lakes NJ, USA) and was immediately centrifuged for 15 min at 3000 g (C-28A, BOECO, Germany) for harvesting plasma. Plasma samples (10 ml per cow) were kept at 4°C for 5 h maximum until lipoprotein fractionation. Based on their density, plasma lipoprotein fractions were separated sequentially by
preparative ultracentrifugation in a Sorvall WX Ultra 90 (Thermo Scientific) equipped with a T-865 rotor. Potassium bromide (KBr) was added to plasma to obtain the required density calculated by use of the Radding and Steinberg (1960) formula. Plasma was ultracentrifuged at 291,400 g at 4°C for 21.2 h at a density of 1.006 g/ml to remove the very-low-density lipoprotein (VLDL) fraction, at 291,400 g at 4°C for 26.6 h at a density of 1.063 g/ml to separate the low-density lipoprotein (LDL) and at 365,900 g at 4°C for 26 h to obtain the HDL fraction.

2.3. Fatty acid analysis

Lipids from oils, diets, plasma and lipoproteins were extracted by adaptation of the method by Bligh and Dyer (1959), and methylated according to Chouinard et al. (1999). A gas chromatograph (GC-2010) system (Shimadzu Scientific Instruments AOC-20 s, Columbia, MD, USA) equipped with a 100-m column (Rt-2560 column 100 m × 0.32 mm × 0.20 µm column; Restek, Bellefonte, PA, USA) was used. The column had a highly polar phase and it was bicsyanopropyl polysiloxane – not bonded. The GC conditions were as follows: the oven temperature was initially set at 110°C for 4 min after injection and then ramped to 170°C at 5°C/min for 10 min. The temperature was then ramped to 225°C at 3°C/min and held for 10 min and finally ramped to 240°C at 3°C/min. The inlet and flame ionisation detector temperatures were 260°C, the split ratio was 15:1 and a 2 µl injection volume was used. The hydrogen carrier gas flow to the detector was 25 ml/min, airflow was 400 ml/min and the flow of nitrogen makeup gas was 40 ml/min. FA GC peaks were identified by using a FA methyl ester standard (FAME; Supelco 37 Component FAME mix, Bellefonte, PA, USA) and reference standards for C18:1trans-11 and C18:1cis-9,trans-11 (Nu-Chek-Prep Inc., Elysian, MN, USA).

2.4. Statistical analysis

Data from each group of cows (lactating and non-pregnant) were analysed as a 3 × 3 Latin square using the GenStat (12th edition) statistical package (VSN International Ltd, Oxford, UK). Fixed effects were diet and period, and the random effect was the individual cow. When significant treatment effects were detected, means were separated using Tukey test. Probability of \( p < 0.05 \) was used to determine significant differences among means.

3. Results and discussion

Details of milk production and performance have been reported elsewhere (Vargas-Bello-Pérez et al. 2015). FA composition of the diets is shown in Table 1. As expected, compared with control and SO diets, HPO was characterised by higher concentrations of saturated FA (SFA): 46 g/100 g of C16:0 and 36 g/100 g of C18:0, whereas SO was characterised by higher concentrations of PUFA: C18:2cis-9,12 (50 g/100 g of total FA). It has been shown that diets enriched with PUFA increase lipoprotein fluidity compared with SFA-rich diets, which is relevant because changes in the physical state of lipoproteins can interfere with the physiological roles of lipoproteins and can cause
hypercholesterolemia and decreased fluidity (Scislowski et al. 2004b). Additionally, changes in the FA profile of lipoproteins can contribute to chronic disorders, for example, in humans these can cause inflammatory and immune disorders, neurological dysfunction and deterioration in the coagulation functions (Williams 2000). Supplementing cow diets with either PUFA or SFA may improve performance; however, research is needed to study the consequences on bovine health of long-term modifications in the lipoprotein FA profile.

The concentrations of total lipids in the plasma from lactating cows fed control, SO and HPO diets amounting to 424, 428 and 507 mg/dl, respectively, and from non-lactating cows to 400, 410 and 425, respectively, were not significantly different. Because both groups had different dietary treatments, a comparison was not possible. However, it has been shown (Herdt and Smith 1996) that plasma lipoprotein concentrations are influenced by lactation cycle and dietary fat supplementation in dairy cows. In this study, it appears that physiological state related to lactation may influence the FA profile of plasma and lipoproteins.

In general, our results agree with previous studies where the most abundant FA were C16:0, C18:0 and C18:2\textit{cis}-9,12 (Table 2), which showed how dietary lipid composition can be reflected in the FA concentrations of plasma (Loor et al. 2002; Jacobs et al. 2011) and lipoproteins (McCarthy et al. 1968). In the plasma of lactating cows compared with the control and SO group, the supplementation of HPO increased the concentration of C16:0, C18:0, C18:2\textit{cis}-9,12, C18:3\textit{cis}-9,12,15 and total SFA and PUFA (Table 2). In non-lactating cows, the supplementation of SO increased the concentration of C18:1\textit{trans}-11 in plasma.

In this study, increases in SFA in plasma and some lipoproteins are consistent with the HPO FA profile, which indicated that SFA are the major products leaving the rumen and thus taken up and packed into lipoproteins. In lactating cows, concentrations of C16:0, C18:0 and total SFA in HDL were increased by HPO supplementation.

Table 2. Fatty acid composition of plasma [mg/dl plasma] from lactating and non-lactating cows fed a control diet (C) or diets supplemented with soybean oil (SO) or hydrogenated palm oil (HPO).

| Fatty acids | C | SO | HPO | SED | p | C | SO | HPO | SED | p |
|------------|---|----|-----|-----|---|---|----|-----|-----|---|
| C10:0      | 14.3| 14.9| 15.4| 9.57| 0.99| 16.9| 23.1| 30.7| 11.7| 0.53|
| C14:0      | 1.61| 1.30| 1.71| 0.55| 0.75| 0.50| 1.07| 1.21| 0.33| 0.16|
| C16:0      | 53.0| 55.2| 70.2| 3.61| <0.01| 38.4| 59.3| 65.3| 16.0| 0.28|
| C18:0      | 99.1| 101.3| 117.8| 3.98| <0.01| 68.0| 114| 112| 27.9| 0.25|
| C18:1\textit{trans}-10 | 0.33| 0.05| 0.85| 0.44| 2.26| n.d. | n.d.| n.d.| n.d.| n.d.|
| C18:1\textit{trans}-11 | 0.90| 1.65| 3.06| 1.58| 0.43| 1.31| 6.89| 3.66| 1.87| 0.05|
| C18:1\textit{cis}-9 | 27.5| 32.4| 39.4| 5.08| 0.13| 22.4| 31.0| 30.3| 9.70| 0.63|
| C18:2\textit{cis}-9,12 | 133.0| 134.9| 158.2| 8.00| 0.03| 53.4| 85.9| 83.9| 22.6| 0.34|
| C18:3\textit{cis}-9,12,15 | 3.43| 3.34| 5.10| 0.62| 0.05| 1.98| 2.90| 3.48| 0.85| 0.28|
| C18:2\textit{cis}-9,\textit{trans}-11 | 0.13| 0.56| 0.31| 0.19| 0.03| 0.17| 0.49| 0.45| 0.22| 0.36|
| \(\Sigma\) Saturated | 170.8| 175.5| 209.4| 11.3| 0.02| 125| 199| 213| 51.7| 0.26|
| \(\Sigma\) Monounsaturated | 35.4| 41.5| 47.5| 5.65| 0.18| 26.8| 34.3| 38.0| 11.7| 0.41|
| \(\Sigma\) Polyunsaturated | 188.3| 180.0| 218.0| 9.56| <0.01| 97.0| 145| 149| 40.2| 0.41|
| Other\(^7\) | 29.5| 31.0| 32.5| 2.68| 0.58| 17.6| 22.5| 26.1| 7.40| 0.54|

Notes: *Basal diets of lactating cows were supplemented with 500 g SO and HPO, respectively (per cow and day); †Basal diets of non-lactating cows were supplemented with 170 g SO and HPO, respectively (per cow and day); SED, standard error of the difference; n.d., not detected; \(^7\)Fatty acids unidentified or present at <0.05 mg/dl. Means in the same row with different superscripts differ significantly (\(p \leq 0.05\)).
Total SFA in HDL and VLDL were increased by HPO addition (Table 3). In HDL of non-lactating cows, the concentration of C18:0 was increased by HPO supplementation, whereas the concentration of C18:1trans-11 was increased by SO addition (Table 4).

Because this study was focused on characterisation of the FA profile of plasma lipoproteins from lactating and non-lactating cows supplemented with different lipid sources, only the total lipid fraction in blood plasma and lipoproteins were analysed, which includes cholesterol esters, phospholipids, triacylglycerols and non-esterified FA. The low transfer efficiency of PUFA from diet to milk in cows is explained by the fact that the bovine mammary gland primarily extracts FA from the triacylglycerols and non-esterified FA fractions in blood plasma (Loor et al. 2002), whereas PUFA are specifically incorporated into plasma cholesterol esters and phospholipids (Tyburczy et al. 2008). In order to elucidate this transport mechanism, future research will need to separate plasma and lipoproteins into lipid subgroups.

When unprotected oils, particularly with high content of unsaturated FA such as SO are included in dairy cow diets, an increase in ruminal biohydrogenation intermediates is usually observed (Shingfield et al. 2013). Some of these intermediates (e.g., C18:1trans-10 and C18:2trans-10,cis-12) can affect the expression of several genes involved in lipid metabolism in the mammary gland (Bauman et al. 2011). In this regard, C18:1trans-10 was found in plasma and HDL from lactating cows, although dietary treatment did not affect its concentration; this C18:1 isomer is important because it is related to milk fat depression in lactating ruminants (Bauman et al. 2006) and is an intermediate of ruminal biohydrogenation which affects milk yield and milk fat yield, possibly by altering the average melting point of milk FA (Gama et al. 2008). Tyburczy et al. (2008) reported no difference in C18:1trans-10 concentrations of plasma cholesterol esters, triacylglycerols and phospholipids when cows were abomasally infused with free FA of C18:1cis-9 (45.5 g/d), C18:1trans-9 (41.7 g/d) and C18:1trans-11 (41.4 g/d); however, in that study no fractionation of plasma into lipoprotein fractions was performed.

In lactating cows, compared with control and HPO, supplementation of SO increased the plasma concentration of C18:2cis-9,trans-11 and in non-lactating cows the concentration of C18:1trans-11. In terms of plasma transport of octadecenoic acids, Loor et al. (2002) showed that as a proportion of FA within a lipid fraction, C18:1trans-11 was greatest in plasma triacylglycerols, although Mosley et al. (2006) found the greatest C18:1trans-11 concentration in plasma phospholipids. Those differences were likely related to the absolute concentration of plasma FA in the phospholipids and triacylglycerols fractions as shown by Tyburczy et al. (2008) who found twice the amount of C18:1trans-11 in both phospholipids and triacylglycerols lipid groups.

Lactation stage has an important effect on FA utilisation to satisfy specific requirements for energy and milk fat synthesis (Palmquist 1976). This may be reflected in the different FA profile of lipoprotein lipids found in the current experiment (mid-lactation and non-lactating cows) compared with those reported by Ofer et al. (2001) (mid-lactation cows) and Tyburczy et al. (2008) (mid-lactation cows). In general, concentrations of SFA in lactating cows were slightly higher than those from non-lactating cows; however, physiological stage was confounded with amounts of diet fed. Further research is needed to compare both responses in order to confirm that physiological stage has a direct impact on use of FA and FA transportation within plasma lipoproteins.
Table 3. Fatty acid composition of plasma lipoproteins [mg/dl of plasma] from lactating cows fed a control diet (C) or diets supplemented with soybean oil (SO) or hydrogenated palm oil (HPO).

| Fatty acids          | High-density lipoprotein | Low-density lipoprotein | Very-low-density lipoprotein |
|----------------------|--------------------------|-------------------------|-----------------------------|
|                      | C  | SO | HPO | SED*          | p   | C  | SO | HPO | SED | p   | C  | SO | HPO | SED | p   |
| C10:0                |    |    |     |              |     |    |    |     |     |     |    |    |     |     |     |
| C14:0                |    |    |     |              |     |    |    |     |     |     |    |    |     |     |     |
| C16:0                | 40.5<sup>b</sup> | 37.9<sup>b</sup> | 51.7<sup>a</sup> | 2.06 | <0.01 | 9.9   | 10.4  | 9.7   | 4.42 | 0.98  | 7.39 | 8.13 | 10.2 | 1.25 | 0.14  |
| C18:0                | 76.8<sup>b</sup> | 72.8<sup>b</sup> | 89.8<sup>a</sup> | 3.93 | 0.01 | 17.4 | 15.6  | 13.4 | 5.77 | 0.79  | 7.76 | 7.94 | 8.74 | 1.58 | 0.80  |
| C18:1 trans-10       | 0.24 | 0.16 | 0.08 | 0.23 | 0.81 | n.d. | n.d. | n.d. | – | – | n.d. | n.d. | n.d. | – | – |
| C18:1 trans-11       | 0.44 | 3.00 | 2.16 | 1.66 | 0.36 | 0.22 | 1.54 | 0.67 | 0.54 | 0.12 | n.d. | n.d. | n.d. | – | – |
| C18:1 cis-9          | 23.6 | 27.4 | 30.0 | 2.93 | 0.16 | 4.78 | 5.81  | 3.67 | 1.64 | 0.47 | 0.8 | 0.3 | 0.0 | 0.42 | 0.20 |
| C18:2 cis-9,12       | 113 | 111.3 | 123.5 | 7.61 | 0.29 | 18.0 | 17.7  | 11.7 | 5.46 | 0.47 | 2.23 | 1.62 | 2.16 | 0.48 | 0.43 |
| C18:3 cis-9,12,15    | 2.55 | 3.12 | 3.83 | 0.64 | 0.22 | – | – | – | – | – | 1.32 | 1.63 | 2.01 | 0.29 | 0.13 |
| C18:2 cis-9, trans-11 | 0.10 | 0.13 | 0.06 | 0.11 | 0.79 | – | – | – | – | – | – | – | – | – | – |
| C20:5 n-3            | 1.94 | 2.51 | 3.14 | 0.63 | 0.24 | 0.07 | 0.06 | 0.09 | 0.11 | 0.95 | – | – | – | – | – |
| C20:4 n-6            | 12.9 | 11.2 | 13.7 | 0.86 | 0.06 | 1.94 | 1.61  | 1.26 | 0.66 | 0.62 | – | – | – | – | – |
| C22:6 n-3            | 12.8 | 12.9 | 13.0 | 2.47 | 0.99 | 2.54 | 2.51  | 2.93 | 1.55 | 0.95 | – | – | – | – | – |
| Σ Saturated          | 149.3<sup>b</sup> | 147.1<sup>b</sup> | 190.3<sup>a</sup> | 7.15 | <0.01 | 30.8 | 29.4  | 26.0 | 11.0 | 0.90 | 16.4<sup>b</sup> | 17.4<sup>b</sup> | 20.3<sup>a</sup> | 0.45 | <0.01 |
| Σ Monounsaturated    | 33.0 | 36.9 | 40.5 | 4.31 | 0.29 | 5.86 | 8.22  | 5.22 | 2.25 | 0.43 | 0.84 | 0.29 | 0.0 | 0.42 | 0.20 |
| Σ Polyunsaturated    | 143.3 | 141.2 | 157.3 | 6.58 | 0.09 | 23.2 | 22.5  | 16.4 | 7.08 | 0.59 | 3.55 | 3.25 | 4.17 | 0.33 | 0.07 |
| Other<sup>‡</sup>     | 13.56 | 17.11 | 17.6 | 1.92 | 0.14 | 4.42 | 4.80  | 3.88 | 1.67 | 0.86 | 0.36 | 0.43 | 0.86 | 0.42 | 0.48 |

Notes: †Basal diets of lactating cows were supplemented with 500 g SO and HPO (per cow and day); *SED, standard error of the difference; ‡n.d., not detected; ‡Fatty acids unidentified or present at <0.05 mg/dl. <sup>b</sup>Means in the same row with different superscripts differ significantly (p ≤ 0.05).
Table 4. Fatty acid composition of plasma lipoproteins [mg/dl of plasma] from non-lactating cows fed a control diet (C) or diets supplemented with soybean oil (SO) or hydrogenated palm oil (HPO).†

| Fatty acids | C10:0 | C12:0 | C16:0 | C18:0 | C18:1 trans-11 | C18:1 cis-11 | C18:2 cis-9,12 | C18:2 cis-9,trans-11 | C20:4 n-3 | C22:6 n-3 | C22:6 n-3 | C20:5 n-3 | C20:4 n-6 | C20:4 n-6 | C22:6 n-3 | C20:4 n-6 | C22:6 n-3 | C20:5 n-3 | C20:4 n-6 | C22:6 n-3 | C20:5 n-3 |
|-------------|-------|-------|-------|-------|----------------|-------------|----------------|-------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| **High-density lipoprotein** |       |       |       |       |                |             |                |                   |           |           |           |           |           |           |           |           |           |           |           |           |           |
| C           | 26.7  | 25.7  | 19.5  | 6.54  | 0.52          | n.d.        | n.d.           | n.d.              | –          | –         | –         | –          | –          | –          | –          | –         | –         | –          | –         | –         | –         | –         |
| SO          | n.d.  | n.d.  | n.d.  | n.d.  | –             | 0.04        | 0.01           | 0.03              | 0.02       | 0.56      | 0.82      | 0.76       | 0.88       | 0.24       | 0.89       |           |           |           |           |           |           |           |
| HPO         | 39.8  | 37.9  | 47.8  | 3.48  | 0.06          | 11.5        | 10.5           | 13.7              | 1.06       | 0.06      | 6.56      | 7.80       | 8.36       | 0.70       | 0.10       |           |           |           |           |           |           |           |
| SED*        | 76.6<sup>b</sup> | 76.7<sup>b</sup> | 85.8<sup>a</sup> | 3.43  | 0.05          | 17.6        | 18.1           | 20.3              | 2.19       | 0.47      | 8.56      | 7.04       | 8.00       | 2.16       | 0.78       |           |           |           |           |           |           |           |
| p           | 1.15<sup>b</sup> | 4.33<sup>a</sup> | 1.55<sup>a</sup> | 0.57  | <0.01         | 0.84        | 2.03           | 0.89              | 0.49       | 0.08      | n.d.      | n.d.       | n.d.       | –          | –          |           |           |           |           |           |           |           |
| Low-density lipoprotein |       |       |       |       |                |             |                |                   |           |           |           |           |           |           |           |           |           |           |           |           |           |           |
| C           | 23.1  | 24.5  | 25.1  | 2.38  | 0.72          | 5.42        | 5.18           | 4.71              | 0.46       | 0.35      | 0.2       | 0.3        | 0.33       | 0.61       |           |           |           |           |           |           |           |
| SO          | 37.9  | 77.8  | 77.0  | 7.36  | 0.66          | 10.4        | 10.9           | 10.7              | 1.37       | 0.93      | 1.46      | 2.38       | 1.56       | 1.02       | 0.63       |           |           |           |           |           |           |           |
| HPO         | 2.30  | 25.3  | 3.10  | 0.39  | 0.18          | n.d.        | n.d.           | n.d.              | –          | –         | 1.28      | 1.89       | 1.59       | 0.80       | 0.76       |           |           |           |           |           |           |           |
| SED*        | 0.11  | 0.26  | 0.12  | 0.18  | 0.66          | n.d.        | n.d.           | n.d.              | –          | –         | n.d.      | n.d.       | n.d.       | –          | –          |           |           |           |           |           |           |           |
| C20:4 n-3   | 4.18  | 3.70  | 3.83  | 0.68  | 0.77          | 0.08        | 0.14           | 0.12              | 0.10       | 0.87      | n.d.      | n.d.       | n.d.       | –          | –          |           |           |           |           |           |           |           |
| C20:4 n-6   | 25.9  | 26.0  | 26.3  | 2.91  | 0.98          | 3.54        | 3.43           | 3.37              | 0.77       | 0.97      | n.d.      | n.d.       | n.d.       | –          | –          |           |           |           |           |           |           |           |
| C22:6 n-3   | 14.5  | 13.5  | 15.0  | 1.17  | 0.47          | 2.32        | 2.52           | 1.43              | 0.87       | 0.46      | n.d.      | n.d.       | n.d.       | –          | –          |           |           |           |           |           |           |           |
| **Very-low-density lipoprotein** |       |       |       |       |                |             |                |                   |           |           |           |           |           |           |           |           |           |           |           |           |           |           |
| C           | 163.1 | 160.3 | 173.1 | 9.76  | 0.43          | 32.5        | 31.9           | 37.5              | 3.06       | 0.21      | 16.2      | 15.9       | 17.9       | 1.90       | 0.56       |           |           |           |           |           |           |           |
| SO          | 28.4  | 33.3  | 31.8  | 1.88  | 0.09          | 7.54<sup>b</sup> | 8.11<sup>a</sup> | 6.83<sup>b</sup> | 0.40       | 0.05      | 0.23      | 0.33       | 0.32       | 0.61       |           |           |           |           |           |           |           |
| HPO         | 118.5 | 123.8 | 125.4 | 7.86  | 0.67          | 16.7        | 17.4           | 16.1              | 2.82       | 0.90      | 2.74      | 4.26       | 3.14       | 1.79       | 0.69       |           |           |           |           |           |           |           |
| SED*        | 9.97  | 10.5  | 9.84  | 1.64  | 0.91          | 3.87        | 4.82           | 4.10              | 0.55       | 0.28      | 0.74      | 0.02       | 0.22       | 0.31       | 0.13       |           |           |           |           |           |           |           |
| p           | 9.97  | 10.5  | 9.84  | 1.64  | 0.91          | 3.87        | 4.82           | 4.10              | 0.55       | 0.28      | 0.74      | 0.02       | 0.22       | 0.31       | 0.13       |           |           |           |           |           |           |           |

Notes: †Basal diets of dry non-pregnant cows were supplemented with 170 g SO and HPO (per cow and day); *SED, standard error of the difference; n.d., not detected; $Fatty acids unidentified or present at <0.05 mg/dl. $Means in the same row with different superscripts differ significantly (p ≤ 0.05).
The stearoyl-CoA desaturase (SCD) activity in plasma lipids is a factor that may explain the differences found in the FA profile of plasma lipoproteins in lactating and non-lactating dairy cows. The SCD converts SFA into monounsaturated FAs by introducing a double bond between carbon atoms 9 and 10 in the saturated carbon chain, but it can also catalyse the desaturation of different monounsaturated fatty acyl-CoA substrates, including C18:1\textit{trans}-11 to generate C18:2\textit{cis}-9,\textit{trans}-11 (Jacobs et al. 2011). The consequences of regulating the SCD by PUFA and cholesterol may be relevant to lipoprotein metabolism since liver and adipose cell metabolic homeostasis depend on SCD; for example, the hepatic packaging and secretion of the VLDL require the synthesis of apolipoprotein B-100 as well as sufficient amount of C18:1\textit{cis}-9, which would either come from the diet or from synthesis by SCD (Ntambi 1999).

In the current study, the transesterification of FA was performed with sodium methoxide at low temperature which quickly methylates FA of triglycerides and phospholipids (Christie 1982). It is possible that FA of cholesterol esters were not completely methylated, which is important because more than 90% of plasma FA are carried by the HDL fraction, mainly in cholesterol esters and phospholipids groups (Offer et al. 2001). In the current study, however, the objective was to compare dietary effects on FA profiles of plasma and lipoprotein fractions, not to compare lipid structures. Future studies should use an acid-catalysed transesterification coupled with thin-layer chromatography to confirm complete methylation of cholesterol esters.

4. Conclusions

Overall, it was found that distribution and transport of FA within bovine plasma lipoproteins may be influenced by chain length and degree of unsaturation of dietary lipids. Also, the distribution of individual FA isomers such as C18:1\textit{trans}-11 and C18:2\textit{cis}-9,\textit{trans}-11 may vary depending on the physiological state of cows (lactating or non-lactating) and are increased in plasma (lactating cows) and the HDL (non-lactating cows) when cows’ diets were supplemented with SO.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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