Use of microalgae in ruminant nutrition and implications on milk quality – A Review

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Abstract

Microalgae are photoautotroph unicellular or multicellular microorganisms which are smaller than 400 μm and can be used as an animal feed source. Ruminants seem to be promising targets of this new feedstuff, as they can also use non-protein nitrogens present in algae and digest the cell walls of algal organisms. Despite the potential for use of microalgae in ruminant feeding, to our knowledge the applications are still limited and there are no reviews in the literature on the effects of microalgae on milk yield and quality. This paper reviews the studies on the use of microalgae for dairy ruminant feeding in order to provide complete information on the state of the art, limitations, and their potential use. The major effects of microalgae on milk production are the changes in the milk fatty acid profile, especially related to the long chain fatty acids and the omega 3 series, in particular DHA and EPA which are beneficial for human health. These results are interesting as to date attempts to increase the omega 3 content in milk by feeding have led to limited results, since PUFA biohydrogenation in the rumen is massive. However, excessive algal supplementation might negatively impacts on palatability, feed intake, the ruminal metabolism and may have negative effects on milk production and fat. In conclusion, careful attention should be paid in terms of the amount of algae supplemented and ruminoprotected forms should be considered in order to prevent reductions in the feed intake, and a deterioration in milk yield and quality. Further reseach is needed to identify the more appropriate species/feed and the effects of a prolonged supplementation.

Keywords: microalgae, ruminant feeding, milk quality, omega 3 fatty acids

1. Introduction

Ruminant milk is one the most consumed beverage in the world and its importance for human nutrition and health is well known given its protein, sugar, fat, vitamins and mineral content. In the last twenty years, several studies have focused on improving the nutritional and nutraceutical quality of milk, and at providing it with an added nutritional value.
Research on improving milk composition is also of interest to producers given that dairy industries worldwide have instituted penalty and premium programs to provide incentives for dairy producers to improve milk composition and quality (Draaijer et al., 2009).

In addition to the importance for human health, milk and livestock productions are contributors to global food security, in fact the world population is expected to increase and the demand for foods of animal origin will grow.

At the same time, livestock farming impacts on emissions of pollutants and the degradation of natural resources. For example, livestock farming has an impact in terms of land use, as currently one third of arable land is dedicated to feedstuff production. In this regard, the research on non typical feedstuffs as a substitute for standard ones represents an opportunity, especially in terms of overcoming some of the problems related to the depletion of natural resources, the use of GMO products such as soy, or when the costs of traditionally used feedstuff are very high (Liponi et al., 2007; McAllister et al., 2011).

Microalgae are photoautotroph unicellular or multicellular microorganisms which are smaller than 400 μm. They can be used as an economical unconventional animal feed source, since they are very efficient in converting solar energy, are not dependent on external environmental conditions, and characterized by higher productions per unit area than traditional crops (Priyadarshani and Rath, 2012). Given the above characteristics, microalgae can therefore contribute to reducing the exploitation of natural resources (Holman and Malau-Aduli 2013).

In addition, some species can be grown for biodiesel production (Kovač et al., 2013), and the residual algal mass, partially or totally defatted, can be used as animal feed (Lum et al., 2013; Drewery et al., 2014). Microalgae are also used in the pharmaceutical and cosmetic industries (Christaki et al., 2011, Ribeiro et al., 2017).

In terms of the chemical composition, microalgae are rich in macro-components. Their composition is widely variable due to the algae genus, species and growing conditions (Spalaore et al., 2006; Venckus, et al., 2017). In general, microalgae are composed of (on dry matter): 39-71% of protein, 10-57% of carbohydrates, mainly polysaccharides, cellulose, and starches (Chen et al., 2013); and 6-86% of lipids especially sterols and long chain PUFA fatty acids (Spalaore et al., 2006; Ryckebosch et al., 2014).

Currently in Europe, the microalgae registered as animal feed or ingredients for animal feed (EU regulation 767/2009) are: *Spirulina maxima* and *Spirulina platensis*; genus Schizochytrium. Unlike their common use in feeding aquatic animals, the use of microalgae in feeding terrestrial species is more recent, especially in poultry and pigs. According to Lum et al. (2013) ruminants may be promising users of this new feedstuff, as they can also benefit from the non-protein nitrogens present in algae and digest the cell walls of algal organisms.

Despite their potential use in ruminant feeding, to our knowledge the applications are still limited and there are no reviews in the literature concerning the effects of microalgae on milk yield and quality. This paper
reviews the studies on the use of microalgae for dairy ruminant feeding in order to provide complete
information on the state of the art, the limitations, and their potential use.

2. Feeding trials including microalgae in ruminants

2.1 Effects on dry matter intake

The characteristics of the diets in the studies on the effects of microalgae supplementation on ruminant milk
yield and quality are reported in table 1. The literature has evaluated the integration of three types of
microalgae-based products with different raw fat percentages (RF):

a) whole algal meal and defatted algal meal: the latter have an average RF content of about 5% and consist of
57% partially deoiled microalgae and the 43% soyhulls; b) microalgae-based oils contain 55-56% RF, and c)
dried or freeze-dried algae biomass with RF ranging from 5-60% whose fat can be encapsulated and rumen
protected. Most of the products used for the studies are commercial and are rich in DHA derived from saltwater
microalgae.

Microalgae-based feeds in ruminant diets are introduced in order to supplement the ration, as a source of:

a) energy: used in the partial substitution of corn or concentrate (Boeckaert et al., 2008; Da Silva et al.,
2016), or added to the lipid supplementation (Toral et al., 2010; Stamey et al., 2012),
b) protein: in partial replacement of soy (Reynolds et al., 2006; Póti et al., 2015; Stamm, 2015) or
rapeseed (Lamminen et al., 2017).
c) enhance the antioxidant defence system and oxidant status of products (Tsiplakou et al., 2018) given the
natural content of natural antioxidant compounds.

In table 2 the results of the studies of the effects of microalgae on feed intake, milk yield and quality are shown.

When the supplementation of algal products is exceeded, feed ingestion decreases and in cows fed unifeed, the
intake decreases from 7% to 45% (Boeckart et al., 2006; Moate et al., 2013). Although without recording a
decrease in total feed intake, some authors, have detected qualitative changes in intake. In particular, a
reduction in the intake of the concentrate containing microalgae was balanced by a higher intake of silage
(Lamminen et al., 2017).

In cows, the maximum amount of microalgae ingested without effects on feed intake varies in different studies
in a fairly wide range from 4 to 79 g of microalgae/kg of dry matter in the diet (Weatherly, 2015; Stamm,
2015). The decrease depends on the type of feedstuff, for example products based on algal meal in dairy cows,
are accepted up to inclusions of 10-11 g/kg of the dry matter intake (Boeckart et al., 2008; Moate et al., 2011),
while meal made up of defatted microalgae and soyhulls, appear to be better tolerated, up to 92 g/kg of dry
matter (Da Silva et al., 2016). On the other hand studies on algal oil supplementation have shown that it does
not affect the intake in cows if integrated up to 194 g/day per head (Stamey et al., 2012). In sheep, a reduction
in the intake of concentrate was observed with an algal biomass supplementation of about 12 g / kg (estimated value) of the ration (Papadopoulos et al., 2002).

Three hypotheses have been formulated to explain the changes in feed intake linked to the administration of microalgae. One hypothesis attributes the changes to the low palatability both in sheep and cows (Franklin et al 1999; Papadopoulos et al., 2002; Lamminen et al., 2017). The low acceptability may be due to the taste and odour, to the physical structure of the feed, especially if the microalgae are dry and finely powdered. The palatability could be improved by pelleting the ration (Lamminen et al., 2017). A second explanation is the decrease in fiber digestibility, which is partly linked to the fermentable carbohydrates in the algae and to the small particle size which could have a negative influence on rumen pH (Stokes et al., 2015). A third hypothesis is the disturbance of the rumen fermentation through the PUFA contained in the algae which could have toxic effects on the rumen microflora (Boeckart et al., 2008).

Franklin et al. (1999) ruled out a negative effect of algae fat yield on ruminal metabolism in cows. In fact, in their study, the quantity of fat provided by the experimental diet was comparable with that of the control diet. Toral et al. (2010) also ruled out the negative effects of algal fat yield in sheep. They report that several studies have found that the inclusion of vegetable oils in the diet of dairy sheep does not have apparent negative effects on feed ingestion (Pulina et al., 2006; GómezCortés et al., 2008, Hervás et al., 2008). However, in sheep, only a few studies have analyzed the effects of the inclusion of unprotected lipids of a marine origin.
2.2 Effects on the milk yield

With regard to the effects of microalgae feeding on the quantitative production of milk, it is not straightforward to compare the literature because of the differences in the amount of microalgae supplemented, in the duration of the experiment, and in the composition of the diet.

However, most authors have not found an influence on the milk yield, either in cows or small ruminants, and no effects have also been reported in studies where reductions or changes in the intake were observed (Franklin et al., 1999; Papadopoulos et al., 2002; Moate et al., 2013; Tsiplakou et al., 2017a, 2018; Weatherly, 2015; Lamminen et al., 2017).

Despite reducing feed intake, the dietary addition of algae does not affect milk yield presumably because of the increased feed efficiency (Franklin et al., 1999; Papadopoulos et al., 2002). The increased feed efficiency was probably a result of the direct incorporation of fatty acids from algae into milk fat (Goulas, 2000).

However, the literature also reports cases in which production losses have occurred. For example Boeckaert et al. (2008) showed that a 45% lower milk yield was produced in cows fed algae in quantity of 43.0 g/kg of DM of the ration through the rumen fistula (Boeckaert et al., 2008). Production decreases have also been found in sheep with 25 g/kg of algal biomass of DM of the diet, in diets that also included of corn silage and alfalfa hay silage (Reynolds et al., 2006).

On the other hand, the administration of *Spirulina* (200 g per day, about 10-14 g/kg of DM) led to a higher milk yield in cows with a maximum increase of 25% in daily production during a 90-day experimental period (Kulpys et al., 2009). The authors explained that the improvement was due to the chemical composition of the microalga *Spirulina platensis* which influences both the biological activity of the ruminal flora and physiological status of the animal. Moreover, studies found that total daily intake of water was greater in steers receiving *Spirulina platensis* (Panjaitan et al., 2010), this aspect in dairy cows should be further investigate as the increased water intake could affect milk yield and quality.

In addition, beneficial effects of some microalgae species on metabolic status and defence system of animals as well as on oxidant status of products have been reported. Regarding this latter issue Tsiplakou et al. (2018) found higher superoxide dismutase activity in blood and milk and higher catalase activities in the blood plasma in goats that fed *Chlorella vulgaris*. Superoxide dismutase and catalase are among the main components of the intracellular antioxidant defence mechanisms which regulate reactive oxygen species accumulation within tissues, whereas enzyme lactoperoxidase in milk is related to the oxidation of lipids. In the above reported study also a reduction of anoxidative stress biomarker (protein carbonyls) in milk was found.

2.3 Effects on milk composition

2.3.1 Protein and lactose

Regarding the results of algal supplementation on the synthesis of milk proteins, different results have been reported depending on the species, diet, ingestion, and milk yield.
As a result of adding microalgae, some authors reported no changes in milk proteins in the diet in either cows or sheep and goats (Bichi et al., 2013; Moate et al., 2013; da Silva et al., 2016; Tsiplakou et al., 2017a, 2018).

In contrast, other studies have reported a decrease in protein yield in cows, mainly followed by a decrease in feed intake and milk yield (Boeckaert et al., 2008). Others have also reported a tendency of milk protein to decrease, although not related to decreased intake or milk yield (Lamminen et al., 2017). According to Lamminen et al., (2017) the decrease in milk protein might be due to the low presence of histidine in microalgae. This amino acid limits milk production and may become suboptimal in the case of algal administration.

In sheep, decreases in the percentage of proteins have been found (Papadopulos et al., 2002; Toral et al., 2010). Unlike findings reported in cows by Boeckaert et al. (2008), these differences were not associated with changes in the feed intake, or with negative effects on the rumen microflora.

In sheep Reynolds et al. (2006) observed increases in the daily protein yield with a diet based on pelleted alfalfa hay and algae compared to a diet of corn silage and algae. The authors attributed the increases to the higher intake of protein due to the alfalfa hay. In the same study, decreases in the daily protein yield and increases in percentages were observed in animals fed a diet based on alfalfa hay-silage supplemented with microalgae compared to corn silage; in this case the protein changes were linked to a concentration effect due to the decrease in milk yield.

Contrasting results on the effects of algal supplementation on lactose have also been reported. According to some authors, lactose decreases with the addition of microalgae in cows' feed (Boeckaert et al., 2008) mainly linked to decreases in the milk yield; and decreases in lactose percentages have also been observed in sheep (Papadopulos, 2002; Reynolds et al., 2006). In contrast, other authors have reported lactose increases (Moate et al., 2013), while others have reported no variations (Kulpys et al., 2009; Bichi et al., 2013; Poti et al., 2015; Da Silva et al., 2016; Tsiplakou et al., 2017a, 2018).

1.3.2 Fat

In cows receiving microalgae supplementation, there is a reduction in secreted milk fat (Boeckaert, et al., 2008; Moate et al., 2013; Weatherly, 2015); fat yield decreases range from a minimum loss of 22% to a maximum of 59% (Franklin et al. 1999; Boeckaert, et al., 2008). In addition, low fat percentages have been recorded in both cows and sheep (Franklin et al., 1999; Boeckaert, et al., 2008; Toral et al., 2010; Bichi et al., 2013; Moate et al., 2013; Poti et al., 2015). The decreases are consistent with other studies that have included marine products, such as fish oil, fish meal, or marine algae.

However the literature results on fat also vary, since no significant changes in milk fat have been reported (Stamey et al., 2012; Da Silva et al., 2016; Lamminen et al., 2017; Tsiplakou et al., 2017a, 2018).

Milk fat decreases could be related either to a higher fat content of experimental diets compared to control (Table 1) (Toral et al., 2010) or to a negative energy balance as a result of the low feed intake or to a low fat syndrome related to the accumulation in the rumen of trans fatty acids intermediate in the biohydrogenation
and to the formation in the rumen of C18: 2 isomer inhibitors of lipid synthesis (Boeckaert et al., 2008; Moate et al., 2013). The increase in fat synthesis inhibitors might be related to toxic effects on the ruminal microbiota which did not adapt to the dietary supply of very long chain n-3 polyunsaturated fatty acids (Bichi et al., 2013).

In terms of using vegetable oils in the diet, the fat inhibitor isomers most involved are known and are mainly trans-10, cis-12 C18: 2 and trans-9, cis-11 C18: 2, both in dairy cows and sheep (Shingfield and Grinari, 2007; Sinclair et al., 2010). However, regarding microalgae, the inhibitor isomers are not completely known. Toral et al. (2010) hypothesized the joint action of trans-9, cis-11 C18: 2 and trans-10 C18: 1, together with other unidentified intermediates, whereas according to Boeckaert et al. (2008), the low fat syndrome could be caused by the reduced synthesis of c9 C18: 1. The latter fatty acid is essential to maintain milk fat fluidity, and the synthesis of milk fat is assumed to be inhibited in the case of a c9 C18: 1 reduced secretion (Gama et al., 2008).

On the other hand, some authors have reported increases in the percentage of fat in goats and sheep feeding microalgae (+13-20.0%) (Papadopulos et al., 2002; Reynolds et al. 2006; Poti et al., 2015). In some cases the increases were related to a concentration effect linked to the decrease in milk yield (Reynolds et al. 2006). Other authors have described the increase in fat percentage to the increased forage to concentrate ratio or the experimental diet compared with the control, or to the reduced synthesis trans C18: 1 (n- 7) which has impacts negatively on the milk fat content (Grinari et al. 1998; Papadopulos et al., 2002). Another explanation is the beneficial effects of some algal species on ruminal fermentations (Poti et al., 2015). This hypothesis is also supported by Stamm (2015) who reports increases in the percentage of milk fat (+9%) in cows, which are linked to the beneficial effects of spirulina on rumen.

1.3.3 Milk fat globules

The influence of milk fat globules on milk quality and the factors influencing their size have been reviewed by Martini et al. (2016). Modifications in the ruminant diet can modify the size of the fat globules, thus modulating the contribution of globule bioactive compounds (e.g. MFGM, Spitsberg, 2005) and also affecting the quality characteristics of milk and cheese, as well as the digestibility of milk fat. The diameter of the globules in dairy cows could increase with the increase in the energy supplied by the diet (Carroll et al. 2006, Martini et al., 2010) and with the quantity of fat secreted (Wiking et al., 2004; Martini et al., 2016).

To our knowledge only one study has investigated the effects of microalgae on the number and diameter of milk fat globules (Stamm, 2015). In this study the algae Nannochloropsis, Spirulina and Chlorella, used in the partial substitution of soy, did not influence the average diameter, although the cow diet supplemented with Chlorella affected the number of globules compared to the diet based on Spirulina or Chlorella + Nannochloropsis. The Chlorella treatment also led to a decrease in the number of globules ranging from 1 to 3 microns.

1.3.4 Fatty acid profile of milk

Research on animal feeding has focused on modifying the milk fatty acid profile in order to modulate the content of beneficial elements; and the application of microalgae in this field is quite recent.
The results of the studies of the effects of microalgae supplementation on ruminant milk fatty acids profile are summarised in Table 3.

Infusions of microalgae by ruminal fistula, as well as dietary administration have resulted in saturated fatty acid reductions and increases in polyunsaturated fatty acids (PUFAs) in ruminant milk (from increments of +54% to higher than +100%) (Franklin et al., 1999; Boeckaert et al., 2008; Moate et al., 2013; Poti et al., 2015). These changes were also found in dairy products derived from PUFA-enriched milk (Papadopoulos et al., 2002). Some authors have also observed increases in monounsaturated fatty acids (MUFAs) in goats and cows (+12% and +4% respectively) (Póti et al., 2015; Boeckaert et al., 2008) and increases in total fatty acids de novo synthesized, with a chain length up to C16:0 (Poti et al., 2015; Moate et al., 2013).

Microalgae are also rich in omega 3, which are efficiently transferred into the milk. Studies on cows show how the transfer efficiency is greater in the case of ruminal infusions (with increases of omega 3 of +161%) (Boeckaert et al., 2008), lower, but still considerable with the addition of microalgae in the ration (from +19% to increases higher than 100%) (Stamey et al., 2012; Moate et al., 2013; Póti et al., 2015). Increases have also been recorded in goat's milk (+19% of omega 3) (Póti et al., 2015). These results are interesting as to date attempts to increase the omega 3 content in milk by feeding have led to limited results, since the PUFA biohydrogenation in the rumen is massive (Lock and Bauman, 2004).

Of the fatty acids belonging to the omega 3 series in milk, studies have almost unequivocally reported increases in C22:6 (DHA) as a result of microalgae supplementation. DHA is an essential fatty acid and an important component of the nervous system. An increase in DHA has been observed in cows (Boeckaert et al., 2008; Moate et al., 2013; Póti et al., 2015), goats (Póti et al., 2015) and sheep (Papadopoulos et al., 2002; Reynolds et al., 2006; Bichi et al., 2013), with positive variations ranging from 100 to 1000% or more in cows (Boeckaert et al., 2008; Moate et al., 2013; Póti et al., 2015) + 660% in sheep (Bichi et al., 2013) and +100% in goats (Poti et al., 2015).

However, Weatherly (2015) reported that DHA enrichment occurs at inclusion levels in milk (15 g/kg of dry matter intake) that lead to subacidosis in cows with a reduced intake and low fat secretion in milk. In addition, the percentage of DHA in the milk fat of algae-fed cows - decreases over time. Although the hypothesis is not confirmed by other studies (Bichi et al., 2013), Franklin et al. (1999) suggested that rumen microorganisms may become acclimated to the presence of non ruminoprotected algae in the diet over time, resulting in greater biohydrogenation of DHA with less DHA incorporation into milk fat.

C20:5 (EPA), which is another omega 3 fatty acid beneficial for health, has been found to increase from +17% to +112% in cows (Stamey et al., 2012; Moate et al., 2013; Vahmani et al., 2013) and +133% in goats (Póti et al., 2015) and from 50 to 100% or more in sheep (Papadopoulos et al., 2000; Toral et al., 2010; Bichi et al., 2013) with a microalgae supplemented diet.

In addition, some studies have shown that unsaturated fatty acids with an 18-carbon chain such as linolenic acid (Franklin et al., 1999), linoleic acid (Boeckaert et al., 2008; Franklin et al., 1999) and oleic and stearic
acid decrease with supplementation both in cows and sheep (Papadopoulos et al., 2002; Reynolds et al., 2006; Toral et al., 2010; Moate et al., 2013). The exception is goat's milk in which linoleic acid increases (Kouřimská et al., 2014; Poti et al., 2015).

The CLA fatty acids, and their main isomer C18:2 cis-9, trans-11 whose beneficial effects on the metabolism and anticancer action have been shown in animal models, increase in cow's (from + 13% to +108 %) (Boeckaert et al., 2008; Stamey et al., 2012; Moate et al., 2013; Póti et al, 2015) and sheep milk (+39 %) (Reynolds et al., 2006; Bichi et al., 2013). Similarly, increases in vaccenic acid (C18:1 trans 11) have been observed in cow's (from + 11% to + 203%) (Boeckaert et al., 2008; Stamey et al., 2012; Moate et al., 2013; Póti et al, 2015) and in goat's milk. (+ 151%) (Póti et al, 2015). The increase in C18:2 cis-9, trans-11 associated with algal meal feed was probably due to the inhibitory effects of algae on the rumen biohydrogenation, and also to the increased ruminal production of the C18:1 trans-11 substrate.

The shift in ruminal beta hydroxybutyrate pathway towards the formation of trans-C18:1 fatty acid has been observed also by Tsiplakou et al. (2017b) in goats fed Chlorella vulgaris. This effect was associated with changes in the Butyrivibrio fibrisolvens population in their rumen liquid.

On the other hand the direct effects of algae on animal metabolism have been ruled out, such as on the activity of the Δ9-desaturase enzyme (Boeckaert et al., 2008; Moate et al., 2013).

3. Conclusions

The literature on the effects of algae on milk production is difficult to compare due to differences in the kinds and amounts of supplementation, type of feed and composition of the diet, the different nutrient profiles among algae feedstuffs, and the duration of the experimental period. The greatest changes have been found in the milk fatty acid profile and are related to the long chain fatty acids and fatty acids of the omega 3 series, especially DHA and EPA. However, excessive algal supplementation seems to have negative effects on palatability, feed intake, the ruminal metabolism, as well as negatively impacting on milk production and fat.

A careful attention should be needed regarding the amount of supplemented algae and rumen-protected forms should be considered in order to prevent reductions in feed intake, and a deterioration in milk yield and quality.

Moreover, the following issue should be further clarified: the effects of microalgae on animal metabolic status and welfare; the possible presence of anti-nutritional factors in the various species and the effects of a prolonged supplementation. In addition, the quality and the organoleptic characteristics of dairy products from animals fed microalga should be deepened.

Furthermore, given the effects of the different cultivation conditions on microalgae compositions, and the several points that have yet to be clarified, at the moment it is still too early to clearly define future applications in the dairy sector.
References


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<table>
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<tr>
<th>Feed/Algal species</th>
<th>Duration of treatment diets</th>
<th>Ether extract of the diets (g on kg of DM)</th>
<th>Raw protein of the diets (g on kg of DM)</th>
<th>NDF of the diets (g on kg of DM)</th>
<th>ADF of the diets (g on kg of DM)</th>
<th>Animal Species</th>
<th>Authors</th>
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<tr>
<td>Defatted meal of <em>Prototheca moriformis</em> (57% microalgae-43% soyhulls)</td>
<td>21 days</td>
<td>C=37.6</td>
<td>C=166</td>
<td>C=333</td>
<td>C=152</td>
<td>Cow</td>
<td>Da Silva et al., 2016</td>
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<td>T=39.5</td>
<td>T=163</td>
<td>T=345</td>
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<td>Market products based on marine algae meal rich in DHA, 375 g/cow per d of algal meal respectively</td>
<td>16 days</td>
<td>T1=28</td>
<td>T1=240</td>
<td>T1=323</td>
<td>T1=291</td>
<td>Cow</td>
<td>Moate et al., 2013</td>
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<td>T3=34</td>
<td>T3=226</td>
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<td>T4=38</td>
<td>T4=226</td>
<td>T4=363</td>
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<td>Market products based on marine algae meal rich in DHA, 25 g of sunflower oil/kg of dry matter, plus 8 g of microalgae/kg of dry matter</td>
<td>54 days</td>
<td>C=58</td>
<td>C=190</td>
<td>C=267</td>
<td>C=174</td>
<td>Sheep</td>
<td>Bichi et al., 2013</td>
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<td>T=57</td>
<td>T=189</td>
<td>T=260</td>
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<td>Market products based on marine algae meal rich in DHA, 25 g of sunflower oil/kg of DM</td>
<td>28 days</td>
<td>C=26</td>
<td>C=161</td>
<td>C=308</td>
<td>C=198</td>
<td>Sheep</td>
<td>Toral et al., 2010</td>
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T4=basal diet plus 25 g of sunflower oil/kg of DM and 24 of microalgae

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<th>Experiment 1</th>
<th>11 days</th>
<th>C=30.7</th>
<th>C=152</th>
<th>C=389</th>
<th>C=213</th>
<th>Cow</th>
<th>Boeckaert et al., 2008</th>
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<tr>
<td>C= basal diet</td>
<td></td>
<td>T=30.4</td>
<td>T=160</td>
<td>T=385</td>
<td>T=212</td>
<td></td>
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</tr>
<tr>
<td>T= h microalgae replaces 17.3% of concentrate of C</td>
<td></td>
<td></td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>Experiment 1:</th>
<th>20 days</th>
<th>Experiment 1:</th>
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<tbody>
<tr>
<td>C= corn silage</td>
<td></td>
<td>Ca=139</td>
<td>Ca=313</td>
<td>Ca=180</td>
</tr>
<tr>
<td>Cb= alfalfa pellets</td>
<td></td>
<td>Ta=136;</td>
<td>Tb=310;</td>
<td>Ta=175;</td>
</tr>
<tr>
<td>Ta, b= C a, b plus soybean oil and micro-algae biomass at 25g/kg of ration DM, in substitution of corn meal</td>
<td></td>
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<tr>
<td>Tb=145;</td>
<td></td>
<td>Tb=337;</td>
<td>Tb=225;</td>
<td></td>
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<tr>
<td>Experiment 2:</td>
<td></td>
<td>Experiment 2:</td>
<td>Experiment 2:</td>
<td></td>
</tr>
<tr>
<td>C= haylage</td>
<td></td>
<td>Ce=162</td>
<td>Ce=361</td>
<td>Ce=271</td>
</tr>
<tr>
<td>Cd=Corn silage</td>
<td></td>
<td>Tc=160;</td>
<td>Tc=366;</td>
<td>Tc=272;</td>
</tr>
<tr>
<td>Cc= haylage</td>
<td></td>
<td>Cd=139</td>
<td>Cd=352</td>
<td>Cd=200</td>
</tr>
<tr>
<td>Cd=Corn silage</td>
<td></td>
<td>Td=133;</td>
<td>Td=353;</td>
<td>Td=199;</td>
</tr>
<tr>
<td>Te, d= Cc, d plus soybean oil and micro-algae 25g/kg of ration DM</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Td=133;</td>
<td></td>
<td>Td=353;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Experiment 3:</td>
<td></td>
<td>Experiment 3:</td>
<td>Experiment 3:</td>
<td></td>
</tr>
<tr>
<td>C= corn silage; Te=C plus soybean oil and micro-algae at 37g/kg of ration DM</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Ce=137</td>
<td></td>
<td>Ce=336</td>
<td>Ce=191</td>
<td></td>
</tr>
<tr>
<td>Te=136</td>
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<td>Te=337</td>
<td>Te=190</td>
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<table>
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<tr>
<th>Experiment 1:</th>
<th>42 days</th>
<th>C=53.4</th>
<th>C=241.8</th>
<th>Fibre=</th>
<th>Sheep</th>
<th>Reynolds et al., 2006</th>
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<tbody>
<tr>
<td>C=basal diet;</td>
<td></td>
<td>T1=40</td>
<td>T1=224.3</td>
<td>C=206.5</td>
<td></td>
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<tr>
<td>T1=C ration with 16.9 g/day of algae;</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>T2=42.6</td>
<td></td>
<td>T2=198.9</td>
<td>T2=201.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T2= C ration with 27.7 g/day algae ;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T3=42.6</td>
<td></td>
<td>T3=198.9</td>
<td>T2=194</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T3= C ration with 51.7 g/day g algae</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>T3=194</td>
<td></td>
<td>T3=194</td>
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Sheep
Papadopoulos et al., 2002
<table>
<thead>
<tr>
<th>Study</th>
<th>Treatment Details</th>
<th>Duration</th>
<th>Experiment 1</th>
<th>Experiment 2</th>
<th>Notes</th>
</tr>
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<tbody>
<tr>
<td><strong>Dry biomass, <em>Spirulina platensis</em></strong></td>
<td>C= basal diet; T= C diet plus 200g of <em>Spirulina platensis</em></td>
<td>90 days</td>
<td>T1=150</td>
<td>T1=475</td>
<td>Cow Kulpys et al., 2009</td>
</tr>
<tr>
<td>i) <em>Spirulina platensis</em>; ii) <em>Clorella vulgaris</em></td>
<td>two experiments tested microalgae feeding compared to diet supplemented with rapeseed meal or without supplementary protein feed</td>
<td>21 days</td>
<td>T1=125</td>
<td>T1=421</td>
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<td></td>
<td>Experiment 1: C=basal diet; T1) C plus pelleted rapeseed; T2) C plus a mixture of S. platensis and C. vulgaris; T3) C plus a mixture of pelleted rapeseed and algae supplement</td>
<td></td>
<td>T2=146</td>
<td>T2=413</td>
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<tr>
<td></td>
<td>Experiment 2: C= basal diet; T1= C plus no protein supplementation; T2= C plus pelleted rapeseed; T3= C plus Spirulina platensis; T4 = C plus mixture of pelleted rapeseed and Spirulina platensis</td>
<td></td>
<td>T3=151</td>
<td>T3=410</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>T4=149</td>
<td>T4=410</td>
<td></td>
</tr>
<tr>
<td><strong>Clorella vulgaris</strong></td>
<td>C= basal diet; T=C plus microalgae</td>
<td>30 days</td>
<td><em>C=20</em></td>
<td>*C=165</td>
<td>goat Tsiplakou et al., 2018</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><em>T=19</em></td>
<td>*T=167</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td><em>C=486</em></td>
<td><em>T=490</em></td>
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<td></td>
<td></td>
<td></td>
<td><em>C=256</em></td>
<td><em>T=269</em></td>
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<tr>
<td><strong>Chlorella pyrenoidosa</strong></td>
<td>C= basal diet; T=C plus microalgae</td>
<td>28 days</td>
<td>C=68</td>
<td>C=110</td>
<td>goat Tsiplakou et al., 2017a</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>T=69</td>
<td>T=115</td>
<td></td>
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<td></td>
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<td>C=294</td>
<td>T=294</td>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ADF=80</td>
<td>T=79</td>
<td></td>
</tr>
<tr>
<td>i) <em>Dried Chlorella kessleri</em></td>
<td>i) C= basal diet; T= C diet plus micro-alga</td>
<td>10 days</td>
<td>i) C=20.9</td>
<td>i) C=201.4</td>
<td>goat Póti et al., 2015</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>T=20.8;</td>
<td>T=209.2;</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>C=254.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ii) C=22.0</td>
<td>ii) C=165.8</td>
<td></td>
</tr>
<tr>
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<tr>
<td>Treatment Description</td>
<td>Diet Combinations</td>
<td>Duration</td>
<td>Effectiveness</td>
<td>Notes</td>
<td></td>
</tr>
<tr>
<td>--------------------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------------------</td>
<td>----------</td>
<td>---------------</td>
<td>---------------------------------</td>
<td></td>
</tr>
<tr>
<td>Dried <em>Spirulina platensis</em></td>
<td>T1= basal diet, T= C diet plus micro-alga</td>
<td>21 days</td>
<td>T=21.9</td>
<td>T=165.5; T=253.8; T=259.2T=258.4</td>
<td></td>
</tr>
<tr>
<td>Powder</td>
<td>C= basal diet</td>
<td></td>
<td></td>
<td>Cow Stamm, 2015</td>
<td></td>
</tr>
<tr>
<td><em>Spirulina platensis</em>; <em>Chlorella vulgaris</em>; <em>Chlorella platensis</em> + Nannochloropsis gaditana (50:50)</td>
<td>T1= C diet plus soya concentrate; T2= C diet plus <em>Spirulina platensis</em>; T3= C diet plus <em>Chlorella vulgaris</em>; T4= C diet plus <em>Chlorella vulgaris</em> + Nannochloropsis gaditana</td>
<td>28 days</td>
<td>Not available</td>
<td>Not available</td>
<td></td>
</tr>
<tr>
<td>Spray dried <em>Schizochytrium sp.</em> heterotrophically grown</td>
<td>T1,2,3,4=0, 100, 300, 600, grams of algae per day respectively</td>
<td>28 days</td>
<td>T1=55.3</td>
<td>T1,2,3,4=158</td>
<td></td>
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<tr>
<td>Commercial products: <em>lipid encapsulated biomass and algal meal</em></td>
<td>C=basal diet</td>
<td>7 days</td>
<td>C=44</td>
<td>C=T1,2,3=146</td>
<td></td>
</tr>
<tr>
<td></td>
<td>T1=C plus 0.5× algal biomass supplement</td>
<td></td>
<td></td>
<td>Cow Stamey et al., 2012</td>
<td></td>
</tr>
<tr>
<td></td>
<td>T2= C plus 1× algal biomass supplement</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>T3= C plus 1× algal oil supplement</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marine algae</td>
<td>C=basal diet diet</td>
<td>C=32.1</td>
<td>C=170</td>
<td>C=266</td>
<td>C=207</td>
</tr>
<tr>
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</tr>
<tr>
<td>Schizochytrium sp</td>
<td>T1=C plus 910g/d</td>
<td>T1=36.5</td>
<td>T1=169.8</td>
<td>T1=264</td>
<td>T1=212.2</td>
</tr>
<tr>
<td>rumino protected and non-protected algae</td>
<td>T2=C plus 910g/d</td>
<td>T2=38.3</td>
<td>T2=169.1</td>
<td>T2=262.6</td>
<td>T2=211.1</td>
</tr>
</tbody>
</table>

C= control, T1, 2, 3, 4= treatments

1. Da Silva et al., 2016. Basal diet: total mixed ration (TMR). Ingredients (g/kg of dry matter) (DM): corn silage: 501; ground corn: 269; soybean meal: 113; whole raw soybean: 80.1; minerals and vitamins: 16; sodium bicarbonate: 9; dicalcium phosphate: 4.6; urea: 3.80; limestone: 1.4; magnesium oxide: 1.10; salt: 0.90; ammonium sulfate 0.5

2. Moate et al., 2013. Basal diet: 5.9 kg of dry matter per day of concentrates (683 g/kg of cracked wheat (Triticum aestivum), 250 g/kg of cold-pressed canola, 46 g/kg of granulated dried molasses, and 21 g/kg of mineral mix) and ad libitum alfalfa (Medicago sativa) hay.


5. Boeckaert et al., 2008. Experiment 1 basal diet: TMR. Ingredients (g/kg of DM): grass silage 333; corn silage: 333; standard dairy concentrate: 306; soybean meal: 27.8

6. Reynolds et al., 2006. Ingredients of the basal diets (g/kg of DM): Experiment 1/Control diet a: corn silage: 600; corn meal: 186.6; soybean meal: 173.5; mono-Na phosphate: 10.95; limestone: 20; trace mineral salt: 5; vitamin A: 0.07; vitamin D: 0.18; vitamin E: 0.88; selenium (201 mg/kg): 2.70; zinc oxide (730 g Zn/kg): 0.08. Experiment 1/Control diet b: alfalfa meal: 600; corn meal: 381.8; mono-Na phosphate: 10.95; trace mineral salt: 5; vitamin A: 0.07; vitamin D: 0.18; vitamin E: 0.88; selenium (201 mg/kg): 1; zinc oxide (730 g Zn/kg): 0.08.

7. Papadopulos et al. 2002. Basal diets: 600 g pelleted alfalfa hay and concentrate according to milk production at a rate of 1 kg of concentrate for each 1±7 kg milk.

8. Kulpys et al., 2009. Basal diets: 15 kg of silage and haylage, 2 kg of hay and an additional 350 g of combined fodder per 1 litre of milked milk after calving for indoor animal. For animal at pasture the diet was 60 kg of grass, 100 g vitamin-mineral supplements and 300 g of combined fodder per 1 litre of milked milk.

9. Lamminen et al., 2017. Ingredients of the basal diets (g/kg of DM): Experiment 1: 9.801 kg of DM cereal-sugar beet pulp-based concentrate + silage of primary growth of timothy (Phleum pratense) and meadow fescue (Festuca pratensis) mixture ad libitum. Experiment 2: 10.78 of DM of concentrate cereal-sugar beet pulp-based concentrate + silage of secondary growth of timothy (Phleum pratense) and meadow fescue (Festuca pratensis) mixture ad libitum.

11. Tsiplakou et al., 2017a. Basal diet consisted in alfalfa hay, wheat straw and concentrates with a forage/concentrate ratio of 50/50. The concentrate (g/kg as fed) consisted of: maize grain: 340; barley grain: 380; soybean meal: 150; wheat middlings: 110; calcium phosphate: 15; salt: 3; mineral and vitamin premix: 2.


15. Franklin et al., 1999. Basal diet: TMR. Ingredients (g/kg of DM): alfalfa hay: 350; corn silage: 125; corn grain: 331; soybean meal: 101; dry distiller’s grains: 44.6; dicalcium phosphate: 10.6; molasses: 7.5; limestone: 8.4; sodium bicarbonate: 7.8; tallow: 4.9; trace minerals: 4.2; magnesium oxide: 1.9, vitamins A, D and E premix: 1.4; vitamin E premix: 0.7.
Table 2. Results of the studies of the effects of microalgae supplementation on ruminant milk yield and quality

<table>
<thead>
<tr>
<th>Feed/Algal species</th>
<th>Raw fat of integration (% on DM)</th>
<th>Raw protein of integration (% on DM)</th>
<th>Animal Species</th>
<th>Maximum quantity of microalgae in the diet without affecting the intake</th>
<th>Effects on milk yield</th>
<th>Effects on milk proteins</th>
<th>Effects on milk lactose</th>
<th>Effects on milk fat</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Defatted meal of <em>Prototheca moriformis</em> (57% microalgae-43% soyhulls)</td>
<td>5.4%</td>
<td>7.6%</td>
<td>Cow</td>
<td>92 g/kg of the DM of the diet</td>
<td>Not significant</td>
<td>Not significant</td>
<td>Not significant</td>
<td>Not significant</td>
<td>Da Silva et al., 2016</td>
</tr>
<tr>
<td>Market products based on marine algae meal rich in DHA</td>
<td>Not available</td>
<td>Not available</td>
<td>Cow</td>
<td>Up to 5 g/kg of DMI, the intake (T2) decreases for higher quantities</td>
<td>Not significant</td>
<td>Not significant</td>
<td>Not significant</td>
<td>Not significant</td>
<td>Increase starts with supplementations higher than 11 g/kg di DMI (T3 and T4) and percentage with supplementations starting from 5g/kg of DMI (T2)</td>
</tr>
<tr>
<td></td>
<td>56%</td>
<td>16.7%</td>
<td>Sheep</td>
<td>8g/kg of the DM of the diet</td>
<td>Not significant</td>
<td>Not significant</td>
<td>Not significant</td>
<td>Not significant</td>
<td>Decrease in yield (kg/die) and percentage with supplementations from 8 g/kg of DM of the diet (T3)</td>
</tr>
<tr>
<td></td>
<td>56.7</td>
<td>17%</td>
<td>Sheep</td>
<td>Up to 24 g/kg of the DM of the diet (T4)</td>
<td>Not significant</td>
<td>Not available</td>
<td>Decrease of yield (kg/die) and percentage with supplementations from 8 g/kg of DM of the diet (T3)</td>
<td>Toral et al., 2010</td>
<td></td>
</tr>
<tr>
<td></td>
<td>58%</td>
<td></td>
<td>Cow</td>
<td>Decrease with supplementations of 10g/kg of DMI</td>
<td>Decrease in yield kg/die</td>
<td>Decrease in concentration (g/kg) from 25g/kg of dry</td>
<td>Decrease in yield kg/die and percentage (with the prolongation of the supplementation)</td>
<td>Boeckaert et al., 2008</td>
<td></td>
</tr>
<tr>
<td></td>
<td>39%</td>
<td>17%</td>
<td>Sheep</td>
<td>Decrease with integration up to 25 g/kg of DM of the diet</td>
<td>Decrease</td>
<td>Increase in concentration (g/kg) from 25g/kg of DM</td>
<td>Increase in concentration (g/kg) from 25g/kg of dry</td>
<td>Increase in concentration (g/kg) from 25g/kg of DM</td>
<td>Reynolds et al., 2006</td>
</tr>
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</table>
Based on alfalfa pellets or alfalfa haylage (Tb and Tc); no effect with 37 g/kg of DM if the diet is based on insilicate (Te).

<table>
<thead>
<tr>
<th>Diet</th>
<th>Animal</th>
<th>Effect Description</th>
<th>Reference</th>
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</thead>
<tbody>
<tr>
<td>Alfalfa pellets or alfalfa haylage (Tb and Tc)</td>
<td>Sheep</td>
<td>Decrease in concentrate intake with 12 g/kg of DM of the diet (T2) (estimated value)</td>
<td>Papadopoulos et al., 2002</td>
</tr>
<tr>
<td>Diet based on alfalfa hay and alfalfa haylage (Tb and Tc)</td>
<td>Cow</td>
<td>Decrease in percentage from 12 g/kg of DM of the diet (T2) (estimated value)</td>
<td>Kulpys et al., 2009</td>
</tr>
<tr>
<td>Diet based on higher supplements in the diet based on corn silage diet (Ta, Te)</td>
<td></td>
<td>Decrease in daily yield</td>
<td>Lamminen et al., 2017</td>
</tr>
<tr>
<td>Alfalfa hay is fed (Tb) and decreases in daily yield</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alfalfa haylage is fed (Tb and Tc); no significant effects on daily yield</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
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### Dry biomass, *Spirulina platensis’s*

<table>
<thead>
<tr>
<th>Percent</th>
<th>Animal</th>
<th>Description</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>5%</td>
<td>Cow</td>
<td>Increase</td>
<td>Kulpys et al., 2009</td>
</tr>
<tr>
<td>65%</td>
<td>Cow</td>
<td>Not significant</td>
<td>Not significant</td>
</tr>
<tr>
<td>10-14g/kg of DM (estimated value)</td>
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<td>Not significant</td>
<td>Not significant</td>
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</table>

### Lyophilized *Chlorella vulgaris*

<table>
<thead>
<tr>
<th>Percent</th>
<th>Animal</th>
<th>Description</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.05%</td>
<td>Goat</td>
<td>Increase</td>
<td>Tsiplakou et al., 2018</td>
</tr>
<tr>
<td>67.7%</td>
<td>Goat</td>
<td>Not significant</td>
<td>Not significant</td>
</tr>
<tr>
<td>5.15 g/kg DM (estimated value)</td>
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<td>Not significant</td>
<td>Not significant</td>
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</tbody>
</table>

### Lyophilized *Chlorella pyrenoidosa*

<table>
<thead>
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<th>Percent</th>
<th>Animal</th>
<th>Description</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.03%</td>
<td>Goat</td>
<td>Not significant</td>
<td>Not significant</td>
</tr>
<tr>
<td>57.4%</td>
<td>Goat</td>
<td>Not significant</td>
<td>Not significant</td>
</tr>
<tr>
<td>5 g/kg DMI (estimated value)</td>
<td></td>
<td>Not significant</td>
<td>Not significant</td>
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</table>

### Dried *Chlorella kessleri*

<table>
<thead>
<tr>
<th>Percent</th>
<th>Animal</th>
<th>Description</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.2%</td>
<td>Goat</td>
<td>Increase in percentage</td>
<td>Not significant</td>
</tr>
<tr>
<td>7.4 g/kg of DMI (estimated value)</td>
<td></td>
<td>Not significant</td>
<td>Not significant</td>
</tr>
</tbody>
</table>

### Dried *Spirulina platensis*

<table>
<thead>
<tr>
<th>Animal</th>
<th>Description</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goat</td>
<td>Not significant</td>
<td>Not significant</td>
</tr>
<tr>
<td>Cow</td>
<td>Not significant</td>
<td>Not significant</td>
</tr>
<tr>
<td>50 g</td>
<td>Not available</td>
<td>Not available</td>
</tr>
<tr>
<td>70 g</td>
<td>Not available</td>
<td>Not available</td>
</tr>
<tr>
<td>Description</td>
<td>Percentage</td>
<td>Availability</td>
</tr>
<tr>
<td>-----------------------------------------------------------------------------</td>
<td>------------</td>
<td>--------------</td>
</tr>
<tr>
<td>iv) <em>Spirulina platensis</em>; v) <em>Chlorella vulgaris</em>; vi) <em>Chlorella vulgaris</em> +<em>Nannochloropsis gaditana</em> (50:50)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>iii) 19.2% (Nannochloropsis)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>iii) 79g of DM of the diet</td>
<td></td>
<td></td>
</tr>
<tr>
<td>with <em>Spirulina</em> vs <em>Chlorella</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spray dried Schizochytrium sp. heterotrophically grown</td>
<td>60%</td>
<td>Not available</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Commercial products: lipid encapsulated biomass and algal meal</td>
<td>l.</td>
<td>Cow</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marine algae Schizochytrium sp rumino procted and non ruminoprotected</td>
<td>i) 19% unprotected</td>
<td>Not available</td>
</tr>
<tr>
<td></td>
<td>ii) 25% protected</td>
<td></td>
</tr>
</tbody>
</table>

DM dry matter; DMI dry matter intake
Table 3. Results of the studies of the effects of microalgae supplementation on ruminant milk fatty acids

<table>
<thead>
<tr>
<th>Fatty acid</th>
<th>Maximum variations reported</th>
<th>Species</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>C4:0</td>
<td>i) +19%</td>
<td>Goat</td>
<td>Poti et al., 2015</td>
</tr>
<tr>
<td></td>
<td>ii) -27%</td>
<td>cow</td>
<td>Poti et al., 2015</td>
</tr>
<tr>
<td></td>
<td>iii) +22%</td>
<td>cow</td>
<td>Moate et al., 2013</td>
</tr>
<tr>
<td>C6:0</td>
<td>i) -19%</td>
<td>Cow</td>
<td>Poti et al., 2015</td>
</tr>
<tr>
<td></td>
<td>ii) -35%</td>
<td>sheep</td>
<td>Papadopoulos et al., 2002</td>
</tr>
<tr>
<td>C8:0</td>
<td>i) -10%</td>
<td>cow</td>
<td>Poti et al., 2015</td>
</tr>
<tr>
<td></td>
<td>ii) +12%</td>
<td></td>
<td>Moate et al., 2013</td>
</tr>
<tr>
<td>C10:0</td>
<td>i) +11%</td>
<td>Cow</td>
<td>Moate et al., 2013</td>
</tr>
<tr>
<td></td>
<td>ii) -25%</td>
<td>sheep</td>
<td>Papadopoulos et al., 2002</td>
</tr>
<tr>
<td>C14:0</td>
<td>i) +7%</td>
<td>Cow</td>
<td>Moate et al., 2013</td>
</tr>
<tr>
<td></td>
<td>ii) +28</td>
<td>Sheep</td>
<td>Papadopoulos et al., 2002</td>
</tr>
<tr>
<td></td>
<td>iii) +160</td>
<td>sheep</td>
<td>Total et al., 2012</td>
</tr>
<tr>
<td>C16:0</td>
<td>i) -5%</td>
<td>Cow</td>
<td>Moate et al., 2013</td>
</tr>
<tr>
<td></td>
<td>ii) +21</td>
<td>Sheep</td>
<td>Papadopoulos et al., 2002</td>
</tr>
<tr>
<td></td>
<td>iii) -26%</td>
<td>Sheep</td>
<td>Total et al., 2012</td>
</tr>
<tr>
<td></td>
<td>iv) +7%</td>
<td>Goats</td>
<td>Tsiplakou et al., 2017a</td>
</tr>
<tr>
<td>De novo up C16*</td>
<td>+4%</td>
<td>Cow</td>
<td>Moate et al., 2013</td>
</tr>
<tr>
<td>C18:0</td>
<td>i) -79%</td>
<td>cows</td>
<td>Moate et al., 2013</td>
</tr>
<tr>
<td></td>
<td>ii) From -64% to 91%</td>
<td>sheep</td>
<td>Toral et al., 2010; Reynolds et al., 2006; Papadopoulos et al., 2002</td>
</tr>
<tr>
<td>t11-C18:1</td>
<td>i) from +11% to +203%</td>
<td>cow's</td>
<td>Boeckaert et al., 2008; Stamey et al., 2012; Moate et al., 2013; Póti et al, 2015</td>
</tr>
<tr>
<td></td>
<td>ii) +151%</td>
<td>goat's</td>
<td>Póti et al, 2015</td>
</tr>
<tr>
<td>CLA isomers</td>
<td>i) from +13% to +108%</td>
<td>cow's</td>
<td>Boeckaert et al., 2008; Stamey et al., 2012; Moate et al., 2013; Póti et al, 2015</td>
</tr>
<tr>
<td></td>
<td>ii) +28%</td>
<td>in goat's</td>
<td>Póti et al, 2015</td>
</tr>
<tr>
<td></td>
<td>iii) +39%</td>
<td>sheep milk</td>
<td>Reynolds et al., 2006; Bichi et al., 2013</td>
</tr>
<tr>
<td>e9-C18:1</td>
<td>i) +44%</td>
<td>cow</td>
<td>Franklin et al., 1999</td>
</tr>
<tr>
<td></td>
<td>ii) sheep</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FA</td>
<td>Range</td>
<td>Species</td>
<td>Reference</td>
</tr>
<tr>
<td>---------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>------------------------------------------------</td>
</tr>
<tr>
<td>C18:2</td>
<td>-10%</td>
<td>cow</td>
<td>Boeckaert et al., 2008; Franklin et al., 1999;</td>
</tr>
<tr>
<td></td>
<td>+26%</td>
<td>goat</td>
<td>Moate et al., 2013</td>
</tr>
<tr>
<td></td>
<td>+10%</td>
<td>sheep</td>
<td>Kouřimská et al., 2014; Poti et al., 2015</td>
</tr>
<tr>
<td>n-3 C18:3</td>
<td>-13%</td>
<td>cow</td>
<td>Franklin et al., 1999; Moate et al., 2013</td>
</tr>
<tr>
<td>C20:5</td>
<td>From +17% to +112%</td>
<td>cows</td>
<td>Stamey et al., 2012; Moate et al., 2013; Vahmani et al., 2013</td>
</tr>
<tr>
<td></td>
<td>+133%</td>
<td>goats</td>
<td>Póti et al., 2015</td>
</tr>
<tr>
<td></td>
<td>from +50 to 100% or more</td>
<td>sheep</td>
<td>Póti et al., 2015</td>
</tr>
<tr>
<td></td>
<td>+660%</td>
<td>goats</td>
<td>Boeckaert et al., 2008; Moate et al., 2013; Poti et al., 2015</td>
</tr>
<tr>
<td></td>
<td>+100%</td>
<td>sheep</td>
<td>Bichi et al., 2013</td>
</tr>
<tr>
<td>C22:6</td>
<td>from 100 to 1000% or more</td>
<td>cows</td>
<td>Boeckaert et al., 2008; Moate et al., 2013; Poti et al., 2015</td>
</tr>
<tr>
<td></td>
<td>+660%</td>
<td>goats</td>
<td>Boeckaert et al., 2008; Moate et al., 2013; Poti et al., 2015</td>
</tr>
<tr>
<td></td>
<td>+100%</td>
<td>sheep</td>
<td>Bichi et al., 2013</td>
</tr>
<tr>
<td></td>
<td>+54%</td>
<td>cows</td>
<td>Franklin et al., 1999; Boeckaert et al., 2008; Moate et al., 2013; Póti et al, 2015</td>
</tr>
<tr>
<td></td>
<td>+13%</td>
<td>goat</td>
<td>Póti et al, 2015</td>
</tr>
<tr>
<td>Omega 3</td>
<td>+161%</td>
<td>Milk of cow ruminal infusions</td>
<td>Boeckaert et al., 2008; Stamey et al., 2012; Moate et al., 2013; Póti et al, 2015</td>
</tr>
<tr>
<td></td>
<td>+19% higher than 100%</td>
<td>Milk of cow feeding of microalgae goat's milk</td>
<td>Boeckaert et al., 2008; Stamey et al., 2012; Moate et al., 2013; Póti et al, 2015</td>
</tr>
<tr>
<td></td>
<td>+19%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

De novo = Sum (C4.0 to C15:0) + 0.5*(C16:0 + C16:1).