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**A review of fatty acid profiles and antioxidant content in grass-fed and grain-fed beef**

C.A. Daley<sup>1</sup>, A.Abbott<sup>1</sup>, S.P. Doyle<sup>1</sup>, G. Nader<sup>2</sup>, and S. Larson<sup>2</sup>

College of Agriculture, California State University, Chico<sup>1</sup>

University of California Cooperative Extension Service, Davis, CA<sup>2</sup>

Corresponding author: Cynthia A. Daley, Ph.D., College of Agriculture, California State University, Chico, 400 West 1<sup>st</sup> Street, Chico, CA 95929-0310; Phone: (530) 898-6280;

FAX: (530) 898-5845; Email: [cdaley@csuchico.edu](mailto:cdaley@csuchico.edu)

Email addresses:

CAD: [cdaley@csuchico.edu](mailto:cdaley@csuchico.edu)

AA: [aabbott1@mail.csuchico.edu](mailto:aabbott1@mail.csuchico.edu)

SPD: [pdoyle@csuchico.edu](mailto:pdoyle@csuchico.edu)

GAN: [ganader@ucdavis.edu](mailto:ganader@ucdavis.edu)

SL: [slarson@ucdavis.edu](mailto:slarson@ucdavis.edu)

1

2 **Abstract:**

3 Growing consumer interest in grass-fed beef products has raised a number of questions  
4 with regard to the perceived differences in nutritional quality between beef from grass-  
5 fed and grain-fed cattle. A number of reports spanning three decades suggest that grass-  
6 based diets (including pasture forages) can alter the fatty acid composition of beef,  
7 particularly with respect to known antioxidants such as conjugated linoleic acid (CLA)  
8 and omega-3 fatty acids (n-3). Reports also suggest that grass-fed beef contains higher  
9 levels of  $\beta$ -carotene and  $\alpha$ -tocopherol that are precursor compounds for the synthesis of  
10 Vitamins A and E, respectively. Further, grass-finished beef tends to be lower in overall  
11 fat as compared to grain-fed beef, another attribute to consider as society works to reduce  
12 their overall consumption of dietary fat. The intent of this article is to summarize  
13 information currently available to support the enhanced nutrient claim for grass-fed beef  
14 products, as well as report what is generally known in regard to the impact these nutrients  
15 have on human health.

16

17 **Review Contents:**

18 1. Introduction

19 2. Fatty acid profile in grass-fed beef

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3 9. Conclusion

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5

## 6 **Introduction:**

7 There is considerable support among the nutritional communities for the diet-heart (lipid)  
8 hypothesis, the idea that an imbalance of dietary cholesterol and fats are the primary  
9 cause of atherosclerosis and cardiovascular disease (CVD) [1]. Health professionals  
10 world wide recommend a reduction in the overall consumption of saturated fatty acids  
11 (SFA), trans-fatty acids (TA) and cholesterol, while emphasizing the need to increase  
12 intake of n-3 polyunsaturated fats [1,2]. Such broad sweeping nutritional  
13 recommendations with regard to fat consumption are largely due to epidemiologic studies  
14 showing strong positive correlations between intake of SFA and the incidence of CVD, a  
15 condition believed to result from the concomitant rise in serum low-density-lipoprotein  
16 (LDL) cholesterol as SFA intake increases [3,4]. For example, it is generally accepted  
17 that for every 1% increase in energy from SFA, LDL cholesterol levels reportedly  
18 increase by 1.3 to 1.7 mg/dL (0.034 to 0.044 mmol/L) [5-7].

19

20 Wide promotion of this correlative data spurred an anti-SFA campaign that reduced  
21 consumption of dietary fats, including most animal proteins such as meat, dairy products  
22 and eggs over the last 3 decades [8], indicted on their relatively high SFA and cholesterol  
23 content. However, more recent lipid research would suggest that not all SFAs have the

1 same impact on serum cholesterol. For instance, lauric acid (C12:0) and myristic acid  
2 (C14:0), have a greater total cholesterol raising effect than palmitic acid (C16:0), whereas  
3 stearic acid (C18:0) has a neutral effect on the concentration of total serum cholesterol,  
4 including no apparent impact on either LDL or HDL. Lauric acid increases total serum  
5 cholesterol, although it also decreases the ratio of total cholesterol:HDL because of a  
6 preferential increase in HDL cholesterol [5,7,9]. Thus, the individual fatty acid profiles  
7 tend to be more instructive than broad lipid classifications with respect to subsequent  
8 impacts on serum cholesterol, and should therefore be considered when making dietary  
9 recommendations for the prevention of CVD.

10

11 Clearly the lipid hypothesis has had broad sweeping impacts; not only on the way we eat,  
12 but also on the way food is produced on-farm. Indeed, changes in animal breeding and  
13 genetics have resulted in an overall leaner beef product[10]. Preliminary examination of  
14 diets containing today's leaner beef has shown a reduction in serum cholesterol, provided  
15 that beef consumption is limited to a three ounce portion devoid of all external fat [11].  
16 O'Dea's work was the first of several studies to show today's leaner beef products can  
17 reduce plasma LDL concentrations in both normal and hyper-cholesterolemic subjects,  
18 theoretically reducing risk of CVD [12-15].

19

20 Beyond changes in genetics, some producers have also altered their feeding practices  
21 whereby reducing or eliminating grain from the ruminant diet, producing a product  
22 referred to as "grass-fed" or "grass-finished". Historically, most of the beef produced  
23 until the 1940's was from cattle finished on grass. During the 1950's, considerable

1 research was done to improve the efficiency of beef production, giving birth to the  
2 feedlot industry where high energy grains are fed to cattle as means to decrease days on  
3 feed and improve marbling (intramuscular fat: IMF). In addition, U.S. consumers have  
4 grown accustomed to the taste of grain-fed beef, generally preferring the flavor and  
5 overall palatability afforded by the higher energy grain ration[16]. However, changes in  
6 consumer demand, coupled with new research on the effect of feed on nutrient content,  
7 have a number of producers returning to the pastoral approach to beef production despite  
8 the inherent inefficiencies.

9

10 Research spanning three decades suggests that grass-only diets can significantly alter the  
11 fatty acid composition and improve the overall antioxidant content of beef. It is the intent  
12 of this review, to synthesize and summarize the information currently available to  
13 substantiate an enhanced nutrient claim for grass-fed beef products as well as to discuss  
14 the effects these specific nutrients have on human health.

15

### 16 **Review of fatty acid profiles in grass-fed beef:**

17

18 Red meat, regardless of feeding regimen, is nutrient dense and regarded as an important  
19 source of essential amino acids, vitamins A, B<sub>6</sub>, B<sub>12</sub>, D, E, and minerals, including iron,  
20 zinc and selenium [17,18]. Along with these important nutrients, meat consumers also  
21 ingest a number of fats which are an important source of energy and facilitate the  
22 absorption of fat-soluble vitamins including A, D, E and K. According to the ADA,  
23 animal fats contribute approximately 60% of the SFA in the American diet, most of

1 which are palmitic acid (C16:0) and stearic acid (C18:0). Stearic acid has been shown to  
2 have no net impact on serum cholesterol concentrations in humans[17,19]. In addition,  
3 30% of the FA content in conventionally produced beef is composed of oleic acid  
4 (C18:1) [20], a group of isomers classified as monounsaturated FAs (MUFAs) that elicit  
5 a cholesterol-lowering effect among other healthful attributes including a reduced risk of  
6 stroke and a significant decrease in both systolic and diastolic blood pressure in  
7 susceptible populations [21].

8

9 Be that as it may, changes in finishing diets of conventional cattle can alter the lipid  
10 profile in such a way as to improve upon this nutritional package. Although there are  
11 genetic, age related and gender differences among the various meat producing species  
12 with respect to lipid profiles and ratios, the effect of animal nutrition is quite significant  
13 [22]. Regardless of the genetic makeup, gender, age, species or geographic location,  
14 direct contrasts between grass and grain rations consistently demonstrate significant  
15 differences in the overall fatty acid profile and antioxidant content found in the lipid  
16 depots and body tissues [22-24].

17

18 Table 1 summarizes the saturated fatty acid analysis for a number of studies whose  
19 objectives were to contrast the lipid profiles of cattle fed either a grain or grass diets [25-  
20 31]. This table is limited to those studies utilizing the *longissimus dorsi* (loin eye),  
21 thereby standardizing the contrasts to similar cuts within the carcass and limits the  
22 comparisons to cattle between 20 and 30 months of age. Unfortunately, not all studies  
23 report data in similar units of measure (i.e., g/g of fatty acid), so direct comparisons  
24 between studies are not possible.

1

2 **Insert Table 1**

3 Table 1 reports that grass finished cattle are typically lower in total fat as compared to  
4 grain-fed contemporaries. Interestingly, there is no consistent difference in total SFA  
5 content between these two feeding regimes until the individual SFA composition is  
6 considered. Those SFA's considered to be more detrimental to serum cholesterol levels,  
7 i.e., myristic (C14:0) and palmitic (C16:0), tend to be higher in grain-fed beef as  
8 compared to grass-fed contemporaries. Grass finished meat contains elevated  
9 concentrations of stearic acid (C18:0), the only saturated fatty acid with a net neutral  
10 impact on serum cholesterol. Thus, grass finished beef produces a more favorable SFA  
11 composition although little is known of how grass-finished beef would ultimately impact  
12 serum cholesterol levels in hyper-cholesterolemic patients as compared to a grain-fed  
13 beef.

14

15 Like SFA intake, dietary cholesterol consumption has also become an important issue to  
16 consumers. Interestingly, beef's cholesterol content is similar to other meats (beef 73;  
17 pork 79; lamb 85; chicken 76; turkey 83 and shrimp 127 mg/100g) [32], and can  
18 therefore be used interchangeably with white meats to reduce serum cholesterol levels in  
19 hyper-cholesterolemic individuals[11,33]. Studies have shown that breed, nutrition and  
20 sex do not affect the cholesterol concentration of bovine skeletal muscle, rather  
21 cholesterol content is highly correlated to IMF concentrations[34]. As IMF levels rise, so  
22 goes cholesterol concentrations per gram of tissue [35]. Because pasture raised beef is  
23 lower in overall fat [24-27,30], particularly with respect to marbling or IMF [36], it

1 would seem to follow that grass-finished beef would be lower in overall cholesterol  
2 content although the data is very limited. Garcia et al (2008) report 40.3 and 45.8 grams  
3 of cholesterol/100 grams of tissue in pastured and grain-fed steers, respectively (P<0.001)  
4 [24].

5  
6 Interestingly, grain-fed beef consistently produces higher concentrations of MUFAs as  
7 compared to grass-fed beef, which include FAs such as oleic acid (C18:1 *cis*-9), the  
8 primary MUFA in beef. A number of epidemiological studies comparing disease rates in  
9 different countries have suggested an inverse association between MUFA intake and  
10 mortality rates to CVD [3,21]. Even so, grass-fed beef provides a higher concentration of  
11 *trans* vaccenic acid (C18:1 *t*11) (TVA), an important MUFA for de novo synthesis of  
12 conjugated linoleic acid (CLA: C18:2 *c*-9, *t*-11) within the body tissues [37].

13  
14 The important polyunsaturated fatty acids (PUFAs) in conventional beef are linoleic acid  
15 (C18:2), alpha-linolenic acid (C18:3), described as the essential FAs, and the long-chain  
16 fatty acids including arachidonic acid (C20:4), eicosapentaenoic acid (C20:5),  
17 docosapentaenoic acid (C22:5) and docosahexaenoic acid (C22:6) [38]. The significance  
18 of nutrition on fatty acid composition is clearly demonstrated when profiles are examined  
19 by omega 6 (n-6) and omega 3 (n-3) families. Table 2 shows no significant change to the  
20 overall concentration of n-6 FAs between feeding regimens, although grass-fed beef  
21 consistently shows a higher concentrations of n-3 FAs as compared to grain-fed  
22 contemporaries, creating a more favorable n-6:n-3 ratio. There are a number of studies

1 that report positive effects of improved n-3 intake on CVD and other health related issues  
2 discussed in more detail in the next section.

3

#### 4 **Review of Omega-3: Omega-6 fatty acid content in grass-fed beef:**

5 There are two essential fatty acids (EFAs) in human nutrition:  $\alpha$ -linolenic acid ( $\alpha$ LA), an  
6 omega-3 fatty acid; and linoleic acid (LA), an omega-6 fatty acid. The human body  
7 cannot synthesize essential fatty acids, yet they are critical to human health; for this  
8 reason, EFAs must be obtained from food. Both  $\alpha$ LA and LA are polyunsaturated and  
9 serve as precursors of other important compounds. For instance,  $\alpha$ LA is the precursor for  
10 the omega-3 pathway. Likewise, LA is the parent fatty acid in the omega-6 pathway.  
11 Omega-3 (n-3) and omega-6 (n-6) fatty acids are two separate distinct families, yet they  
12 are synthesized by some of the same enzymes; specifically, delta-5-desaturase and delta-  
13 6-desaturase. Excess of one family of FAs can interfere with the metabolism of the other,  
14 reducing its incorporation into tissue lipids and altering their overall biological effects  
15 [39]. Figure 1 depicts a schematic of n-6 and n-3 metabolism and elongation within the  
16 body [40].

17

#### 18 **Insert Figure 1**

19

20 A healthy diet should consist of roughly one to four times more omega-6 fatty acids than  
21 omega-3 fatty acids. The typical American diet tends to contain 11 to 30 times more  
22 omega -6 fatty acids than omega -3, a phenomenon that has been hypothesized as a  
23 significant factor in the rising rate of inflammatory disorders in the United States[40].

1 Table 2 shows significant differences in n-6:n-3 ratios between grass-fed and grain-fed  
2 beef, with an overall average of 1.53 and 7.65 for grass-fed and grain-fed, respectively,  
3 for all studies reported in this review.

4

5 The major types of omega-3 fatty acids used by the body include:  $\alpha$ -linolenic acid  
6 (C18:3n-3,  $\alpha$ LA), eicosapentaenoic acid (C20:5n-3, EPA), docosapentaenoic acid  
7 (C22:5n-3, DPA), and docosahexaenoic acid (C22:6n-3, DHA). Once eaten, the body  
8 converts  $\alpha$ LA to EPA, DPA and DHA, albeit at low efficiency. Studies generally agree  
9 that whole body conversion of  $\alpha$ LA to DHA is below 5% in humans, the majority of  
10 these long-chain FAs are consumed in the diet. [41].

11

12 The omega-3 fatty acids were first discovered in the early 1970's when Danish  
13 physicians observed that Greenland Eskimos had an exceptionally low incidence of heart  
14 disease and arthritis despite the fact that they consumed a diet high in fat. These early  
15 studies established fish as a rich source of n-3 fatty acids. More recent research has  
16 established that EPA and DHA play a crucial role in the prevention of atherosclerosis,  
17 heart attack, depression and cancer [40,42]. In addition, omega-3 consumption reduced  
18 the inflammation caused by rheumatoid arthritis [43,44].

19

20 The human brain has a high requirement for DHA; low DHA levels have been linked to  
21 low brain serotonin levels, which are connected to an increased tendency for depression  
22 and suicide. Several studies have established a correlation between low levels of omega -  
23 3 fatty acids and depression. High consumption of omega-3 FAs is typically associated

1 with a lower incidence of depression, a decreased prevalence of age-related memory loss  
2 and a lower risk of developing Alzheimer's disease [45-51].

3  
4 The National Institutes of Health has published recommended daily intakes of FAs;  
5 specific recommendations include 650 mg of EPA and DHA, 2.22 g/day of  $\alpha$ LA and 4.44  
6 g/day of LA. However, the Institute of Medicine has recommended DRI (dietary  
7 reference intake) for LA (omega-6) at 12 to 17 g and  $\alpha$ LA (omega-3) at 1.1 to 1.6 g for  
8 adult women and men, respectively. Although seafood is the major dietary source of n-3  
9 fatty acids, a recent fatty acid intake survey indicated that red meat also serves as a  
10 significant source of n-3 fatty acids for some populations [52].

11  
12 Sinclair and co-workers were the first to show that beef consumption increased serum  
13 concentrations of a number of n-3 fatty acids including, EPA, DPA and DHA in humans  
14 [40]. Likewise, there are a number of studies that have been conducted with livestock  
15 which report similar findings, i.e., animals that consume rations high in precursor lipids  
16 produce a meat product higher in the essential fatty acids [53,54]. For instance, cattle fed  
17 primarily grass significantly increased the omega-3 content of the meat and also produced  
18 a more favorable omega-6 to omega-3 ratio than grain-fed beef. [46,55-57].

19

20 **Insert Table 2**

21

22 Table 2 shows the effect of ration on polyunsaturated fatty acid composition from a  
23 number of recent studies that contrast grass-based rations to conventional grain feeding

1 regimens [24-28,30,31]. Grass-based diets resulted in significantly higher levels of  
2 omega-3 within the lipid fraction of the meat, while omega-6 levels were left unchanged.  
3 In fact, as the concentration of grain is increased in the grass-based diet, the concentration  
4 of n-3 FAs decreases in a linear fashion. Grass-finished beef consistently produces a  
5 higher concentration of n-3 FAs (without effecting n-6 FA content), resulting in a more  
6 favorable n-6:n-3 ratio.

7

8

9 The amount of total lipid (fat) found in a serving of meat is highly dependent upon the  
10 feeding regimen as demonstrated in Tables 1 and 2. Fat will also vary by cut, as not all  
11 locations of the carcass will deposit fat to the same degree. Genetics also play a role in  
12 lipid metabolism creating significant breed effects. Even so, the effect of feeding regime  
13 is a very powerful determinant of fatty acid composition and the overall healthfulness of  
14 the final meat product.

15

## 16 **Review of conjugated linoleic acid (CLA) and *trans* vaccenic acid (TVA)** 17 **in grass-fed beef:**

18

19 Conjugated linoleic acids (CLA) make up a group of polyunsaturated FAs found in meat  
20 and milk from ruminant animals and exist as a general mixture of conjugated isomers of  
21 LA. Of the many isomers identified, the *cis*-9, *trans*-11 CLA isomer (also referred to as  
22 ruminic acid or RA) accounts for up to 80-90% of the total CLA in ruminant products  
23 [58]. Naturally occurring CLAs originate from two sources: bacterial isomerisation

1 and/or biohydrogenation of polyunsaturated fatty acids (PUFA) in the rumen and the  
2 desaturation of trans-fatty acids in the adipose tissue and mammary gland [59,60].  
3  
4 Microbial biohydrogenation of LA and  $\alpha$ LA by an anaerobic rumen bacterium  
5 *Butyrivibrio fibrisolvens* is highly dependent on rumen pH [61]. Grain consumption  
6 decreases rumen pH, reducing *B. fibrisolvens* activity, conversely grass-based diets  
7 provide for a more favorable rumen environment for subsequent bacterial synthesis [62].  
8 Rumen pH may help to explain the apparent differences in CLA content between grain  
9 and grass-finished meat products (see Table 2). De novo synthesis of CLA from 11*t*-  
10 C18:1 *trans* vaccenic acid (TVA) has been documented in rodents, dairy cows and  
11 humans. Studies suggest a linear increase in CLA synthesis as the TVA content of the  
12 diet increased in human subjects [63]. The rate of conversion of TVA to CLA has been  
13 estimated to range from 5 to 12% in rodents to 19 to 30% in humans[64]. True dietary  
14 intake of CLA should therefore consider native 9*c*11*t*-C18:2 (actual CLA) as well as the  
15 11*t*-C18:1 (potential CLA) content of foods [65,66]. Figure 2 portrays de novo synthesis  
16 pathways of CLA from TVA [37].  
17  
18 The impact of feeding practices becomes even more evident in light of recent reports  
19 from Canada which suggests a shift in the predominate *trans* C18:1 isomer in grain-fed  
20 beef. Dugan et al (2007) reported that the major *trans* isomer in beef produced from a  
21 73% barley grain diet is 10*t*-18:1 (2.13% of total lipid) rather than 11*t*-18:1 (TVA)  
22 (0.77% of total lipid), a finding that is not particularly favorable considering the data that  
23 would support a negative impact of 10*t*-18:1 on LDL cholesterol and CVD [67,68].

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**Insert Figure 2**

Over the past two decades numerous studies have shown significant health benefits attributable to the actions of CLA, as demonstrated by experimental animal models, including actions to reduce carcinogenesis, atherosclerosis, and onset of diabetes [69-71]. Conjugated linoleic acid has also been reported to modulate body composition by reducing the accumulation of adipose tissue in a variety of species including mice, rats, pigs, and now humans [72-75]. These changes in body composition occur at ultra high doses of CLA, dosages that can only be attained through synthetic supplementation that may also produce ill side-effects, such as gastrointestinal upset, adverse changes to glucose/insulin metabolism and compromised liver function [76-80]. A number of excellent reviews on CLA and human health can be found in the literature [61,81-83].

Natural augmentation of CLA c9t11 and TVA within the lipid fraction of beef products can be accomplished through diets rich in grass and lush green forages, owing to a more favorable rumen pH for *B. fibrisoloven* and the biohydrogenation pathway. While precursors can be found in both grains and lush green forages, grass-fed ruminant species have been shown to produce 2 to 3 times more CLA than ruminants fed in confinement on high grain diets, largely due to a more favorable rumen pH [34,56,57,84] (see Table 2).

1 Optimal dietary intake remains to be established for CLA. It has been hypothesized that  
2 95 mg CLA/day is enough to show positive effects in the reduction of breast cancer in  
3 women utilizing epidemiological data linking increased milk consumption with reduced  
4 breast cancer[85]. Ha et al. (1989) published a much more conservative estimate stating  
5 that 3 g/day CLA is required to promote human health benefits[86]. Ritzenthaler et al.  
6 (2001) estimated CLA intakes of 620 mg/day for men and 441 mg/day for women are  
7 necessary for cancer prevention[87]. Obviously, all these values represent rough  
8 estimates and are mainly based on extrapolated animal data. What is clear is that we as a  
9 population do not consume enough CLA in our diets to have a significant impact on  
10 cancer prevention or suppression. Reports indicate that Americans consume between 150  
11 to 200 mg/day, Germans consumer slightly more between 300 to 400 mg/day[87], and  
12 the Australians seem to be closer to the optimum concentration at 500 to 1000 mg/day  
13 according to Parodi (1994) [88].

14

### 15 **Review of pro-Vitamin A/ $\beta$ -carotene in grass-fed meat:**

16 Carotenoids are a family of compounds that are synthesized by higher plants as natural  
17 plant pigments. Xanthophylls, carotene and lycopene are responsible for yellow, orange  
18 and red coloring, respectively. Ruminants on high forage rations pass a portion of the  
19 ingested carotenoids into the milk and body fat in a manner that has yet to be fully  
20 elucidated. Ultimately, the carotenoids produce a slight yellowing of the milk or external  
21 fat as evidence of a high forage ration.

22

23 **Insert Table 3**

1

2 Plant species, harvest methods, and season, all have significant impacts on the carotenoid  
3 content of forage. In the process of making silage, haylage or hay, as much as 80% of the  
4 carotenoid content is destroyed [89]. Further, significant seasonal shifts occur in  
5 carotenoid content owing to the seasonal nature of plant growth.

6

7 Carotenes (mainly  $\beta$ -carotene) are precursors of retinol (Vitamin A), a critical fat-soluble  
8 vitamin that is important for normal vision, bone growth, reproduction, cell division, and  
9 cell differentiation [90]. Specifically, it is responsible for maintaining the surface lining  
10 of the eyes and also the lining of the respiratory, urinary, and intestinal tracts. The overall  
11 integrity of skin and mucous membranes is maintained by vitamin A, creating a barrier to  
12 bacterial and viral infection [15,91]. In addition, vitamin A is involved in the regulation  
13 of immune function by supporting the production and function of white blood cells  
14 [12,13].

15

16 The current recommended intake of vitamin A is 3,000 to 5,000 IU for men and 2,300 to  
17 4,000 IU for women [92], respectively, which is equivalent to 900 to 1500  $\mu\text{g}$   
18 (micrograms) (Note: DRI as reported by the Institute of Medicine for non-pregnant/non-  
19 lactating adult females is 700  $\mu\text{g}/\text{day}$  and males is 900 $\mu\text{g}/\text{day}$  or 2,300 – 3,000 I U  
20 (assuming conversion of 3.33 IU/ $\mu\text{g}$ ). While there is no RDA (Required Daily  
21 Allowance) for  $\beta$ -carotene or other pro-vitamin A carotenoids, the Institute of Medicine  
22 suggests consuming 3 mg of  $\beta$ -carotene daily to maintain plasma  $\beta$ -carotene in the range

1 associated with normal function and a lowered risk of chronic diseases (NIH: Office of  
2 Dietary Supplements).

3  
4 The effects of grass feeding on beta-carotene content of beef was described by Descalzo  
5 et al. (2005) who found pasture-fed steers incorporated significantly higher amounts of  
6 beta-carotene into muscle tissues as compared to grain-fed animals [93]. Concentrations  
7 were 0.45  $\mu\text{g/g}$  and 0.06  $\mu\text{g/g}$  for beef from pasture and grain-fed cattle respectively,  
8 demonstrating a 7 fold increase in  $\beta$ -carotene levels for grass-fed beef over the grain-fed  
9 contemporaries. Similar data has been reported previously, presumably due to the high  $\beta$ -  
10 carotene content of fresh grasses as compared to cereal grains[38,55,94-96]. (see Table 3)

11  
12  
13  
14 **Review of Vitamin E/ $\alpha$ -tocopherol in grass-fed beef:**

15  
16 Vitamin E is also a fat-soluble vitamin that exists in eight different isoforms with  
17 powerful antioxidant activity, the most active being  $\alpha$ -tocopherol [97]. Numerous studies  
18 have shown that cattle finished on pasture produce higher levels of  $\alpha$ -tocopherol in the  
19 final meat product than cattle fed high concentrate diets[23,28,93,96,98-100] (see Table  
20 4).

21  
22  
23 Antioxidants such as vitamin E protect cells against the effects of free radicals. Free  
24 radicals are potentially damaging by-products of metabolism that may contribute to the  
25 development of chronic diseases such as cancer and cardiovascular disease.

26

1 **Insert Table 4**

2

3 Preliminary research shows vitamin E supplementation may help prevent or delay  
4 coronary heart disease [101-104]. Vitamin E may also block the formation of  
5 nitrosamines, which are carcinogens formed in the stomach from nitrates consumed in the  
6 diet. It may also protect against the development of cancers by enhancing immune  
7 function [105]. In addition to the cancer fighting effects, there are some observational  
8 studies that found lens clarity (a diagnostic tool for cataracts) was better in patients who  
9 regularly used vitamin E [106,107]. The current recommended intake of vitamin E is 22  
10 IU (natural source) or 33 IU (synthetic source) for men and women [92,108],  
11 respectively, which is equivalent to 15 milligrams by weight.

12

13 The concentration of natural  $\alpha$ -tocopherol (vitamin E) found in grain-fed beef ranged  
14 between 0.75 to 2.92  $\mu\text{g/g}$  of muscle whereas pasture-fed beef ranges from 2.1 to 7.73  
15  $\mu\text{g/g}$  of tissue depending on the type of forage made available to the animals (Table 4).  
16 Grass finishing increases  $\alpha$ -tocopherol levels three-fold over grain-fed beef and places  
17 grass-fed beef well within range of the muscle  $\alpha$ -tocopherol levels needed to extend the  
18 shelf-life of retail beef ( 3 to 4  $\mu\text{g}$   $\alpha$ -tocopherol/gram tissue) [109]. Vitamin E ( $\alpha$ -  
19 tocopherol) acts post-mortem to delay oxidative deterioration of the meat; a process by  
20 which myoglobin is converted into brown metmyoglobin, producing a darkened, brown  
21 appearance to the meat. In a study where grass-fed and grain-fed beef were directly  
22 compared, the bright red color associated with oxymyoglobin was retained longer in the  
23 retail display in the grass-fed group, even though the grass-fed meat contains a higher

1 concentration of more oxidisable n-3 PUFA. The authors concluded that the antioxidants  
2 in grass probably caused higher tissue levels of vitamin E in grazed animals with benefits  
3 of lower lipid oxidation and better color retention despite the greater potential for lipid  
4 oxidation[110].

5

### 6 **Review of antioxidant enzyme content in grass-fed beef:**

7 Glutathione (GT), is a relatively new protein identified in foods. It is a tripeptide  
8 composed of cysteine, glutamic acid and glycine and functions as an antioxidant  
9 primarily as a component of the enzyme system containing GT oxidase and reductase.  
10 Within the cell, GT has the capability of quenching free radicals (like hydrogen  
11 peroxide), thus protecting the cell from oxidized lipids or proteins and prevent damage to  
12 DNA. GT and its associated enzymes are found in virtually all plant and animal tissue  
13 and is readily absorbed in the small intestine[111].

14

15 Although our knowledge of GT content in foods is still somewhat limited, dairy products,  
16 eggs, apples, beans, and rice contain very little GT (< 3.3 mg/100g). In contrast, fresh  
17 vegetables (e.g., asparagus 28.3 mg/100g) and freshly cooked meats, such as ham and  
18 beef (23.3 mg/100g and 17.5 mg/100g, respectively), are high in GT [112].

19

20 Because GT compounds are elevated in lush green forages, grass-fed beef is particularly  
21 high in GT as compared to grain-fed contemporaries. Descalzo et al. (2007) reported a  
22 significant increase in GT molar concentrations in grass-fed beef [113]. In addition,  
23 grass-fed samples were also higher in superoxide dismutase (SOD) and catalase (CAT)

1 activity than beef from grain-fed animals[114]. Superoxide dismutase and catalase are  
2 coupled enzymes that work together as powerful antioxidants, SOD scavenges  
3 superoxide anions by forming hydrogen peroxide and CAT then decomposes the  
4 hydrogen peroxide to H<sub>2</sub>O and O<sub>2</sub>. Grass only diets improve the oxidative enzyme  
5 concentration in beef, protecting the muscle lipids against oxidation as well as providing  
6 the beef consumer with an additional source of antioxidant compounds.

7

### 8 **Issues related to flavor and palatability of grass-fed beef:**

9 Maintaining the more favorable lipid profile in grass-fed beef requires a high percentage  
10 of lush fresh forage or grass in the ration. The higher the concentration of fresh green  
11 forages, the higher the LA and  $\alpha$ LA precursor that will be available for CLA and n-3  
12 synthesis [53,54]. Fresh pasture forages have 10 to 12 times more C18:3 than cereal  
13 grains [115]. Dried or cured forages, such as hay, will have a slightly lower amount of  
14 precursor for CLA and n-3 synthesis. Shifting diets to cereal grains will cause a  
15 significant change in the FA profile and antioxidant content within 30 days of transition  
16 [57].

17

18 Because grass-finishing alters the biochemistry of the beef, aroma and flavor will also be  
19 affected. These attributes are directly linked to the chemical makeup of the final product.  
20 In a study comparing the flavor compounds between cooked grass-fed and grain-fed beef,  
21 the grass-fed beef contained higher concentrations of diterpenoids, derivatives of  
22 chlorophyll call phyt-1-ene and phyt-2-ene, that changed both the flavor and aroma of the  
23 cooked product [116]. Others have identified a “green” odor from cooked grass-fed meat  
24 associated with hexanals derived from oleic and  $\alpha$ LA FAs. In contrast to the “green”

1 aroma, grain-fed beef was described as possessing a “soapy” aroma, presumably from the  
2 octanals formed from LA that is found in high concentration in grains [117]. Grass-fed  
3 beef consumers can expect a different flavor and aroma to their steaks as they cook on the  
4 grill, likewise, because of the lower lipid content and high concentration of PUFAs,  
5 cooking time will be reduced. For an exhaustive look at the effect of meat compounds on  
6 flavor, see Calkins and Hodgen (2007) [118].

7  
8 With respect to palatability, grass-fed beef has historically been less well accepted in  
9 markets where grain-fed products predominant. For example, in a study where British  
10 lambs fed grass and Spanish lambs fed milk and concentrates were assessed by British  
11 and Spanish taste panels, both found the British lamb to have a higher odor and flavor  
12 intensity. However, the British panel preferred the flavor and overall eating quality of the  
13 grass-fed lamb, the Spanish panel much preferred the Spanish fed lamb [119]. Likewise,  
14 the U.S. is well known for producing corn-fed beef, taste panels and consumers who are  
15 more familiar with the taste of corn-fed beef seem to prefer it as well [16]. Consumer  
16 sensory acceptance is a complicated area of research that seems to be influenced largely  
17 by culture and socialization and should be considered more of an art than science.

## 18 19 **Conclusion:**

20 Research spanning three decades supports the argument that grass-fed beef (on a g/g fat  
21 basis), has a more desirable SFA lipid profile (more C18:0 cholesterol neutral SFA and  
22 less C14:0 & C16:0 cholesterol elevating SFAs) as compared to grain-fed beef. Grass-  
23 finished beef is also higher in CLA (C18:2), TVA (C18:1 t11) and n-3 FAs on a g/g fat

1 basis. This results in a better n-6:n-3 ratio that is preferred by the nutritional community.  
2 Grass-fed beef is also higher in precursors for Vitamin A and E and cancer fighting  
3 antioxidants such as GT and superoxide dismutase activity as compared to grain-fed  
4 contemporaries.

5  
6 Grass-fed beef tends to be lower in overall fat content, an important consideration for  
7 those consumers interested in decreasing overall fat consumption. Because of these  
8 differences in FA content, grass-fed beef also possesses a distinct grass flavor and unique  
9 cooking qualities that should be considered when making the transition from grain-fed  
10 beef. To maximize the favorable lipid profile and to guarantee the elevated antioxidant  
11 content, animals should be finished on 100% grass or pasture-based diets.

12  
13 Grain-fed beef consumers may achieve similar intakes of both n-3 and CLA through  
14 consumption of higher fat portions with higher overall palatability scores. A number of  
15 clinical studies have shown that today's lean beef, regardless of feeding strategy, can be  
16 used interchangeably with fish or skinless chicken to reduce serum cholesterol levels in  
17 hypercholesterolemic patients.

18

19 **List of abbreviations:**

20 *c* cis

21 *t* trans

22 FA fatty acid

23 SFA saturated fatty acid

- 1 PUFA polyunsaturated fatty acid
- 2 MUFA monounsaturated fatty acid
- 3 CLA conjugated linoleic acid
- 4 TVA *trans*-vaccenic acid
- 5 EPA eicosapentaenoic acid
- 6 DPA docosapentaenoic acid
- 7 DHA docosahexaenoic acid
- 8 GT glutathione
- 9 SOD superoxide dismutase
- 10 CAT catalase
- 11
- 12 **Competing interests:** no competing interests for any author

13 **Author's contributions:** C.A.Daley was lead author; A Abbott, S Doyle, G Nader  
14 and S Larson were significant contributors and made substantial contributions to  
15 conception, design, and acquisition of data for this review.

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### **Figure Legends:**

Figure 1. Linoleic (C18:2n-6) and  $\alpha$ -Linolenic (C18:3n-3) Acid metabolism and elongation. (Adapted from *Simopoulos et al., 1991*)

Figure 2. De novo synthesis of CLA from 11t-C18:1 vaccenic acid. (Adapted from *Bauman et al., 1999*)

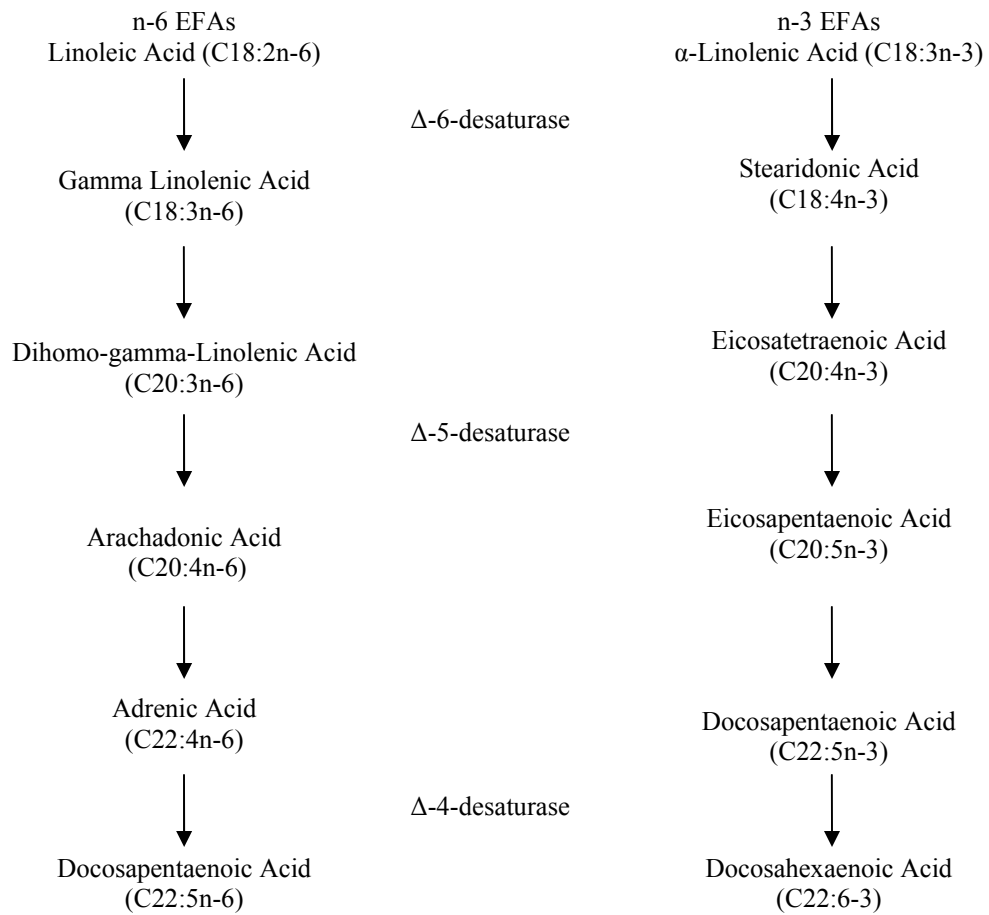
### **Tables Legends:**

**Table 1.** Comparison of mean saturated fatty acid composition (expressed as mg/g of fatty acid or as a % of total lipid) between grass-fed and grain-fed cattle.

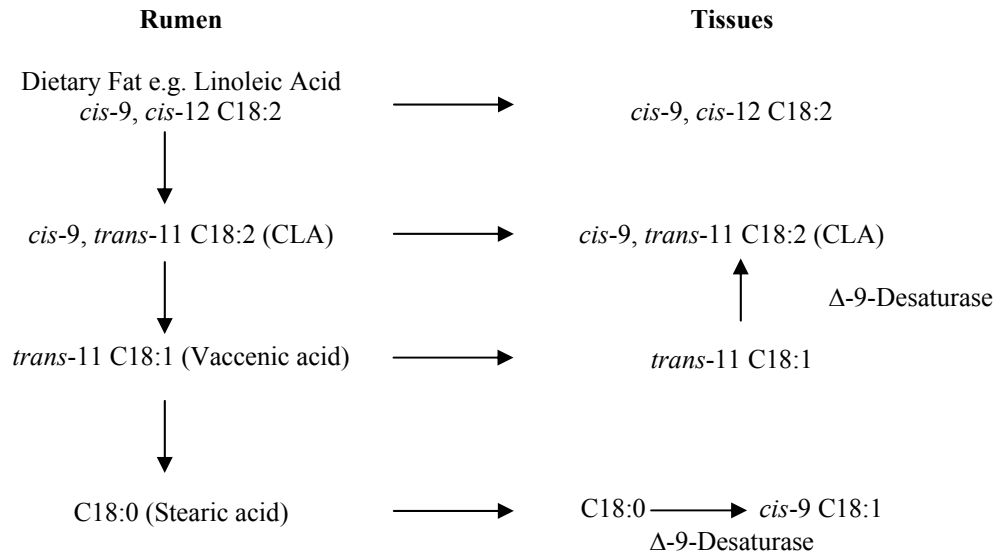
**Table 2.** Comparison of mean polyunsaturated fatty acid composition (expressed as mg/g of fatty acid or as a % of total lipid) between grass-fed and grain-fed cattle.

**Table 3.** Comparison of mean  $\beta$ -carotene vitamin content in fresh beef from grass-fed and grain-fed cattle.

**Table 4.** Comparison of mean  $\alpha$ -tocopherol vitamin content in fresh beef from grass-fed and grain-fed cattle.



**Figure 1. Linoleic (C18:2n-6) and  $\alpha$ -Linolenic (C18:3n-3) Acid metabolism and elongation. (Adapted from *Simopoulos et al., 1991*)**



**Figure 2. De novo synthesis of CLA from 11t-C18:1 vaccenic acid.**  
 (Adapted from *Bauman et al., 1999*)

**Additional files provided with this submission:**

Additional file 1: Table 1\_SFA\_Final.doc, 67K

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Additional file 2: Table 2\_PUFA\_Final.doc, 76K

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Additional file 3: Table 3\_VitA\_Final.doc, 31K

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Additional file 4: Table 4\_VitE\_Final.doc, 35K

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