

Forage-fed cattle point the way forward for beef?

Gillian Butler*, Ali Mohamed Ali, Samson Oladokun, Juan Wang, Hannah Davis

School of Natural and Environmental Science, Agriculture Building, Newcastle University, Newcastle upon Tyne NE1 7RU, UK



A B S T R A C T

Many try to eat sustainably but reliable information is lacking, and environmental impact often prioritises over nutritional quality. Here we consider beneficial fatty acid profiles in steaks from 4 UK systems: non-organic, organic, certified pasture-fed and conservation cattle.

Most individual fatty acids and ratios considered beneficial for health (individual and total omega 3, vaccenic acid and CLA) followed a gradient, against assumed intensity of production. Ratios for linoleic acid: α -linolenic acid, omega-6:omega-3 and SFA:PUFA in pasture-fed sirloins were only 27%, 55% and 70% (respectively) of those in non-organic beef. Intramuscular fat from pasture-fed meat had twice as much omega-3 and 1.9x the long chain omega-3 concentrations compared with non-organic meat, with a ratio of omega-6:omega-3 only 38% of that in non-organic meat.

Meat from 100% pasture-fed and conservation grazing offer *public good*, matching dietary guidelines better than meat from mainstream systems and qualifying as a source of long chain omega-3 fatty acids.

Introduction

For many, food choice is influenced by a desire to be sustainable, possibly considering a wide range of aspects, either in isolation or in combination (Verain et al., 2012; Stampa et al., 2020). For some, the ultimate ethical choice may be avoiding animal products altogether however, a US study calculated the capacity to produce food is greater with *healthy omnivore diets*, rather than exclude animal products (Peters et al., 2016). A high proportion of land is unsuitable for arable crops and only ruminant animals can produce food from many areas across the world.

Depending on animal production systems, there is considerable variation in sustainability (Tallowin et al., 2005; Wolmarans, 2009; Rudolph et al., 2018; Stanley et al., 2018), which consumers or society may be unaware of. A key example relates to food composition; nutritional quality varies, as reported by Daley et al. (2010) and Butler et al. (2011) – yet this is rarely considered with respect to sustainability, despite being crucial for a healthy society. Sustainable diets, defined by the FAO, have a low environmental impact but also contribute to food and nutrition security for public health now and for future generations (FAO, 2012). To this end, European Food Safety Authority (2010) recommends (along with other suggestions) reducing saturated fatty acids (SFA) and omega-6 fatty acids (n-6) and increase omega-3 fatty acids (n-3) intake, especially those with 20 or more carbon atoms. Since metabolism of n-3 and n-6 share common enzyme systems, the widespread excess in dietary n-6 (particularly linoleic acid (LA, c9,12 C18:2)) impairs elongation and desaturation of α -linolenic acid (ALA, c9,12,15 C18:3) necessary for its conversion to eicosapentaenoic acid (EPA, c11,5,18 C20:5 n-3), docosapentaenoic acid (DPA, C22:5 n-3) and ultimately docosahexaenoic acid (DHA, C22:6

n-3) (Simopoulos, 2002; Griffin, 2008). These long chain n-3 (LC n-3) have anti-inflammatory properties and a deficiency contributes to a wide range of health conditions, linked around mental health, cognitive development and deterioration, as well as coronary heart disease (Dyall, 2015; Calder, 2018). A sensible approach for public health would be to identify foods which not only supply more of these pre-formed LC n-3 but also an appropriate balance of LA and ALA, to enhance their endogenous synthesis.

Since pre-history the world's grasslands and associated grazing ruminants co-evolved (Janis et al., 2002; Hackmann and Spain, 2010); animals relying solely on grazing or browsing available vegetation. It is only since mid 20th century we see more concentrated diets, including cereals and cereal or oilseed by-products, fed to our farmed cattle (McDonald et al., 2002). Despite general intensification and loss of grassland diversity in many countries, we have seen a relatively recent movement to reintroduce grazing-only systems in some areas around the world, often under Agri-environmental schemes aimed to recreate lost biodiversity – using cattle or horses to control invasive plant growth and encourage diversity (EnglishNature, 2005; Tallowin et al., 2005). The vegetation accessed by these cattle tends to limit their nutrition, resulting in slower growth and cattle taking longer to reach slaughter condition, possibly older than 3 years (personal communication with the farmers involved). These *systems* may not be considered particularly 'productive' but score highly in 'public-good'; not only enhancing wildlife and livestock diversity (EnglishNature, 2005) but if managed appropriately have also been shown to increase carbon sequestration in grassland soils (Conant et al., 2001; Stanley et al., 2018).

Intensification, replacing grazing and forages in cattle diets, with cereal derived feeds, might increase production rates (McDonald et al., 2002) but fundamentally changes milk and meat composition

* Corresponding author.

E-mail address: gillian.butler@ncl.ac.uk (G. Butler).

Abbreviations used throughout the text and in tables

ALA	α -linolenic acid
CLA	conjugated linoleic acids
CLA9	c9t11 C18:2
DHA	docosahexaenoic acid
DPA	docosapentaenoic acid
EPA	eicosapentaenoic acid
FA	fatty acids
IMF	intramuscular fat
LA	linoleic acid
LC n-3	long chain n-3
MUFA	monounsaturated fatty acids
n-3	omega-3 fatty acids
n-6	omega-6 fatty acids
PFLA	Pasture Fed Livestock Association
PUFA	polyunsaturated fatty acids
SCF	subcutaneous fat
SFA	saturated fatty acids
VA	vaccenic acid

(Alfaia et al., 2006; Daley et al., 2010). Despite extensive changes to dietary lipids by rumen microbiome, cattle diets have the single greatest influence over milk and meat fatty acid profiles (Doreau et al., 2011); replacing forages (rich in n-3) with cereals (dominated by n-6) increases product n-6 content at the expense of n-3. Biohydrogenation in the rumen is responsible for group of beneficial fatty acids; conjugated linolenic acids (CLA), derived directly or indirectly from rumen activity and dominated by the CLA9 isomer (c9t11 C18:2) produced mostly by desaturation of vaccenic acid (VA, t11 C18:1) in the mammary gland or adipose tissue. Like n-3, CLA9 has health benefits, encompassing cardio-vascular health, insulin sensitivity and immune function (Wahle et al., 2004) although in this case perhaps less conclusive (Benjamin et al., 2015). Another common characteristic of the pathways involving metabolism of a) ALA to LC n-3 and b) VA to CLA9 is their occurrence in humans, as well as farmed livestock – Turpeinen et al. (2002) reported our ability to convert 19% of VA to CLA9. Intensification of cattle diets confounds impacts on the supply of EPA, DPA, DHA and CLA9 for meat and dairy consumers since it reduces substrates (ALA and VA) for their synthesis but in the case of LC n-3, also increases competition from LA for their endogenous synthesis - in both the animals' tissues (hence milk and meat) as well as consumers.

Many studies show superior composition of milk and meat from diets dominated by grazing forage, with less LA and n-6, more ALA, n-3, LC n-3, VA and CLA9 as well as lower ratios of LA:ALA and in many cases less saturated fatty acids (SFA), more PUFA and a lower ratio of SFA:PUFA (Scollan et al., 2006; Daley et al., 2010; Kamihiro et al., 2015; Średnicka-Tober et al., 2016a,b). Some studies show staged improvement and suggest products from animal eating a high proportion of grazing are likely to be better for health, enhanced further by diversity within the forage offered (Butler et al., 2008). This theory of healthier products from forage fed animals is reinforced by modelling population diets, comparing meat or milk from grass-fed cattle with those from other production systems. Benbrook et al. (2018), Lenighan et al. (2019) both report superior predicted fatty acid intakes by populations consuming grass fed milk and beef respectively - better matched to guidelines, with greater concentration of known beneficial FA and a more appropriate balance of n-3 to n-6, compared with products from intensive systems.

These environmental and nutritional benefits from ruminants relying solely on forage feeding brought together like-minded UK farmers in 2009, forming the Pasture Fed Livestock Association (PFLA) and subsequently, introducing certification standards (Pasture-for-Life, 2016). Animals kept according to PFLA standards are not fed grain, oilseeds

or manufactured feeds throughout their lifetime. After weaning they rely 100% on forages; grazing when conditions allow or otherwise eating conserved silage or hay. Whilst recent reports considering the superior milk composition from 100% grass-fed cows in US and UK (Benbrook et al., 2018; Davis et al., 2020), to date there are no comparable studies considering nutritional quality of certified 100% grass-fed beef. This paper describes a preliminary study to assess fatty acid profile of steaks from 4 UK production systems, considering the potential impact for consumers health and need for further investigations.

Materials and methods*Sample collections and subsampling*

Sirloin steaks were collected from 2 supermarkets in Newcastle upon Tyne, UK; 5 non-organic and 5 organic steaks were purchased from each shop. They were deliberately collected on several occasions between 20th May to 5th July 2019, using sell-by date, abattoir code and product ID to ensure all originated from different animals. At the same time 9 fresh sirloin steaks were also purchased directly from 2 farms (within 50 miles/80 km of Newcastle) certified as Pasture-Fed. Again, each steak originating from different animals slaughtered in May and early June 2019. Meat (designated as: non-organic, organic and pasture), transported to laboratory on ice packs, was subsampled for intramuscular (IMF) and subcutaneous fat (SCF) as described by Kamihiro et al. (2015) before being frozen.

In addition to these 3 farming systems, 7 steaks were collected from 6 farms elsewhere in England, from cattle kept with the primary function of maintaining biodiversity. Many of these farms were also PFLA members with conservation grazing prescribed under Agri-environmental agreements, covering a range in cattle breeds, landscapes, habitats and vegetation types. These steaks (designated as 'conservation' samples) had been frozen and, whilst from individual animals, did not necessarily originate from cattle killed at the same time of year as others production systems in the study.

Fatty acid analysis

Sample handling, subsampling (for muscle and subcutaneous fat tissues), preparing fatty acid methyl esters (FAME) and their quantification by Gas Chromatography (GC-2014, Shimadzu, Kyoto, Japan) were as described by Kamihiro et al. (2015). A 52 FAME standard allowed identification of individual fatty acids by retention time and areas were quantified relative to the added internal standard (C13:0).

Data analysis

Fatty acid profiles in IMF and SCF were used to calculate results as: a) the amount of fatty acids supplied in a *simulated steak* comprising of 200 g 'lean muscle' (IMF results) and 10 g of subcutaneous fat (SCF results) and b) the concentrations of each FA relative total FA in IMF and SCF tissues. Values for individual FA were used to calculate total SFA, monounsaturated fatty acids (MUFA) and PUFA as well as odd chain fatty acids, total n-3, LC n-3 (EPA+DPA+DHA) and n-6 concentrations and the ratios of LA:ALA, n-6:n-3 and SFA:PUFA.

Analyses of variance (ANOVA) in simulated steaks, IMF and SCF were derived from linear mixed effect models using NLME (Pinheiro et al., 2017) package in the R statistical environment (R Development Core Team, 2009). "Management system" (non-organic, organic, pasture or conservation) were fixed factors and pack number (supermarket) or animal ID (farm sourced) were random factors. Residuals were checked for normality using the QQNORM function (Crawley, 2007) with no deviation.

Table 1

Total and individual fatty acids and calculated values (means in mg/steak \pm standard errors of means) from simulated steaks (comprising of 200 g IMF and 10 g SCF) which differ between production systems or of nutritional relevance.

Production system:	Non-organic <i>n</i> = 10	Organic <i>n</i> = 10	Pasture <i>n</i> = 9	Conservation <i>n</i> = 7	ANOVA <i>p</i> - values
Total fatty acids (g/steak)	11.5 \pm 0.76	11.9 \pm 1.04	8.4 \pm 1.07	8.4 \pm 1.33	*
Individual fatty acids					
C14:0	340 ^{ab} \pm 20.6	432 ^a \pm 40.2	328 ^{ab} \pm 48.2	245 ^b \pm 46.5	*
C14:1	120 ^{ab} \pm 12.8	182 ^a \pm 22.9	141 ^{ab} \pm 27.1	58 ^b \pm 16.8	**
C16:0	3000 ^{ab} \pm 234	3542 ^a \pm 408	2363 ^{ab} \pm 320	1940 ^b \pm 258	**
c9C16:1	533 ^{ab} \pm 40.0	744 ^a \pm 86.1	495 ^{ab} \pm 79.9	337 ^b \pm 73.2	**
t10 C18:1	84 ^a \pm 12.7	25 ^b \pm 7.6	21 ^b \pm 7.6	41 ^{ab} \pm 16.8	***
VA	77 ^b \pm 9.0	108 ^b \pm 19.4	122 ^b \pm 24.1	242 ^a \pm 44.3	***
OA	4427 ^a \pm 424	4568 ^a \pm 544	3006 ^a \pm 405	2516 ^b \pm 371	**
c11 C18:1	188 ^a \pm 19.6	177 ^{ab} \pm 25.1	91 ^b \pm 13.3	94 ^{ab} \pm 34.2	**
LA	190 ^a \pm 24.3	167 ^{ab} \pm 13.0	109 ^b \pm 10.7	107 ^b \pm 12.7	**
ALA	39 \pm 5.1	57 \pm 8.8	58 \pm 6.3	61 \pm 14.2	ns
CLA9	39 \pm 4.5	61 \pm 7.4	50 \pm 7.7	54 \pm 14.2	ns
EPA	11 ^b \pm 3.6	20 ^{ab} \pm 2.4	33 ^a \pm 3.0	33 ^a \pm 5.8	***
DPA	29 \pm 3.5	35 \pm 4.8	34 \pm 4.9	37 \pm 11.6	ns
DHA	11.2 \pm 2.37	12.0 \pm 3.43	14.1 \pm 3.08	19.3 \pm 8.98	ns
Calculated values					
SFA	4917 \pm 359	5445 \pm 649	3702 \pm 514	3669 \pm 503	t
MUFA	5632 \pm 411	5771 \pm 422	4076 \pm 542	3798 \pm 678	*
PUFA	618 \pm 54.3	644 \pm 40.2	625 \pm 52.1	895 \pm 321	ns
n-3	147 \pm 18.3	182 \pm 17.2	207 \pm 15.3	279 \pm 91.6	ns
n-6	383 \pm 37.0	344 \pm 19.9	306 \pm 26.8	415 \pm 129	ns
Long chain n-3	59 \pm 6.8	74 \pm 7.0	87 \pm 7.5	108 \pm 30.4	ns
LA:ALA ratio	5.4 ^a \pm 0.77	3.5 ^b \pm 0.58	2.7 ^b \pm 0.78	1.9 ^b \pm 0.18	**
n-6:n-3 ratio	2.8 ^a \pm 0.39	2.0 ^{ab} \pm 0.19	1.5 ^b \pm 0.78	1.9 ^b \pm 0.18	***
SFA:PUFA ratio	8.3 \pm 0.57	8.4 \pm 0.63	5.8 \pm 0.64	5.6 \pm 1.05	**

Abbreviations:

ANOVA *p*-values: ***=*p*<0.001, **=*p*<0.01, *=*p*<0.05, *t* = 0.05>*p*<0.10, ns *p*>0.1.

Results in the same line with the same superscript letter do not differ significantly according to the tukey honesty difference test (*p*<0.05).

Results

Simulated steak

The supply of 12 individual FA from the simulated steaks which differ between systems are presented in Table 1, along with values for other nutritionally relevant FA and the sum of total quantified fatty acids (giving an indication of total lipid supply from the steaks). For the mid-length FA (14 and 16 carbon atoms) the pattern contrasted with that seen for longer chain FA (C18+). Organic steaks had more C14:0, C14:1, C16:0 and c9 C16:1 than conservation steaks (+94%, 215%, 83% and 120% respectively) with other systems intermediate but not significantly different from either extreme, except C14:1 for pasture steak which (like the organic steak) was higher than conservation meat. Many differences for longer chain FA followed incremental gradients between systems, although not all differences proved significant. For LA and the ratios for LA:ALA and n6:n-3, steak from non-organic \geq organic \geq pasture \geq conservation with the opposite sequence found for VA and EPA - the scale of differences ranging from the lowest value being between 20% and 62% of the highest value. The ratio of SFA:PUFA, supply of oleic acid (OA, c9 C18:1) and MUFA showed similar values for non-organic and organic steak purchased at the supermarkets. Taken together, these were 44%, 67% and 53% higher respectively than values for the steak coming directly from farms, which also did not differ from each other.

Fatty acid concentrations in muscle and fat tissue

The concentrations of FA in IMF and SCF differed significantly between systems (Supplementary Tables S1 and S2). Some differences in FA concentrations, including many of nutritional relevance, were only significant for IMF (Table S1: palmitic acid (PA, C16:0), OA, c12 C18:1,

δ linolenic acid (GLA, C18:3 n-6), ALA, CLA9, EPA, n-3, LC n-3 and LA:ALA and n-6:n-3 ratios) whilst others were restricted to the subcutaneous fat (Table S: C10:0, C14:1, C17:0, C17:1, C18:0, t10 C18:1, LA, C19:1, C20:0, PUFA, n-6, the ratio of SFA:PUFA as well as 7 minor isomers of C18:1 and C18:2 with concentrations less than 0.3% of total FA – results not shown). The total fat in SCF also differed between production systems (Table S); supermarket steaks (non-organic and organic) were similar at 73–77% compared with the 54–55% total FA in SCF from farm sourced steaks. Some FA concentrations differed significantly between production systems in both the IMF and SCF, including t9 C16:1, c9 C16:1, VA, C14/t16 C18:1, t11 c15 C18:2, C20:2 n-6, C20:3 n-6 and the ratio of LA:ALA (Table S2).

These differences in both tissues follow various patterns with a range of similarities and differences between values from the 4 production systems. Some showed a reducing gradient, with values for non-organic \geq organic \geq pasture \geq conservation, as described above for the simulated steaks. In IMF this applied to concentrations of; PA (ranging from 26.4 to 19.6 mg/100 g steak, *p*<0.05), the ratios of LA:ALA (7.0 for non-organic meat vs. 1.9 for pasture meat) and n-6:n-3 (3.8 vs. 1.4) both *p*<0.01). For SCF this pattern applied to the concentration of 2 minor MUFA (c11 C18:1 and C19:1) as well as the ratio of SFA:PUFA (*p*<0.001), which ranged from 19.8:1 in SCF of the non-organic down to a ratio of 9.5:1 for the pasture meat.

However, the concentrations of many nutritionally beneficial FA showed the opposite relationship with increasing concentrations when comparing non-organic \leq organic \leq pasture \leq conservation. For IMF this was significant for VA, ALA, CLA9 and EPA as well as total n-3 and LC n-3. The magnitude in the range of values across these gradients went from ALA in non-organic meat being 48% of that in conservation samples (0.89 vs. 1.87% of total FA, *p*<0.001) down to only 18% for EPA (0.25% in non-organic and 1.34% of total FA for conservation, *p*<0.01).

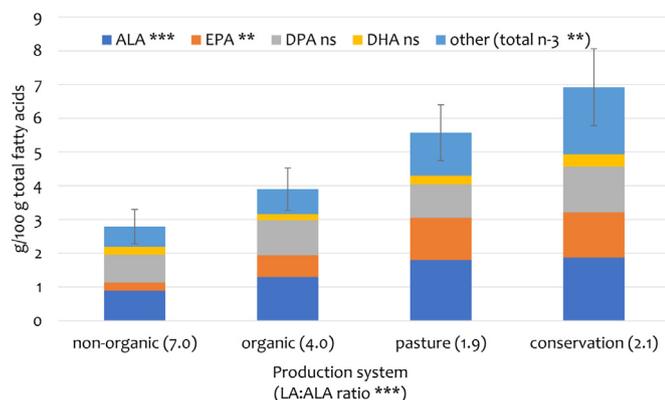


Fig. 1. Omega-3 fatty acids in intramuscular fat from different production systems.

Explanations: Mean value for the concentration of each fatty acid - error-bars represent standard error of means for total omega-3 fatty acids.

Abbreviations: ALA=a-linolenic acid, EPA=eicosapentaenoic acid, DPA=docosapentaenoic acid, DHA=docosahexaenoic acid & ANOVA p -values: ***= $p<0.001$, **= $p<0.01$, ns= $p>0.1$.

Fig. 1 shows the cumulative impact across the production systems on concentrations of individual and total n-3 in IMF ($p<0.001$ for ALA, $p<0.01$ for EPA, $p<0.05$ for n-3 and other differences between systems did not reach significance). In SCF, concentrations of VA and LA followed this pattern across the systems; non-organic SCF contained 22% (0.78% vs. 3.53% of total FA, $p<0.001$) and 37% (0.12% vs. 2.01% total FA, $p<0.01$) as much as SCF from conservation samples, respectively. Although differences between extreme values mentioned here were significant, not all the intermediated concentrations or ratios for meat from other systems reached significance.

Discussion

At first sight fatty acid profiles identified here compare fairly well with other publications (Kamihiro et al., 2015; Lenighan et al., 2019) although there are also noticeable but subtle differences when drilling down into the details, especially for nutritionally relevant FA. Overall, lipids in both IMF and SCF were dominated by palmitic acid (PA, C16:0), stearic acid (SA, C18:0) and oleic acid (OA, c9 C18:0) - together responsible for 74% of FA in the simulated steak, almost 70% in IMF and 77% of those in SCF, with no difference in their sum between the 4 production systems. Nonetheless, this preliminary study did find significant differences for many minor but nutritionally relevant FA and their ratios in meat from the different systems, favouring the pasture and conservation compositions. Given what we knew or assumed about the diets of cattle in the production systems in this study, this is line with expectations. However, without controlled intervention consumer studies, we cannot state with any certainty that meat from these extensive production systems are actually better for us, but the balance of FAs identified here suggests this is highly likely. This discussion will attempt to explain why fatty acid content of steak from these 4 production systems differed and potential implications for consumer diets and health.

One factor influencing meat FA profiles and potentially explaining differences in this study could be seasonality in feeding, as identified by Kamihiro et al. (2015). They report meat from summer is significantly higher in a number beneficial FA (including PUFA and n-3), compared to winter. Although all the supermarket sourced and pasture steaks in this study came from cattle killed between May and June (similar to 'winter' samples in the Kamihiro study), conservation cattle were killed at other times of the year. This is highly likely to influence results, enhancing FA profile from cattle grazing prior to slaughter. Consequently, care is needed in comparing results for conservation meat with those from other systems due to a confounding seasonal influence. For instance, this

probably goes a long way to explain why concentrations of VA (especially in SCF) and to a lesser extent CLA9, were considerably higher in these steaks compared to others; enhanced for some, by summer grazing, as reported by Scollan et al. (2014), Kamihiro et al. (2015) and Lenighan et al. (2019). One way to check the extent seasonal feeding (rather than other factors) influenced composition would be further testing of meat from the other systems, collected at other times of the year, when cattle have the opportunity to graze.

Influence of production system and cattle feeding on fat composition

Although details of cattle diets were unknown for supermarket steaks, previous studies (Butler et al., 2008; Stergiadis et al., 2012) and many years' working with cattle farmers over a range of production systems (Butler, personal communication) suggests both non-organic and organic farms feed some concentrates to finishing cattle prior to slaughter in April and May. The balance of n-3 (from forages) and n-6 (from cereals and their by-product feeds) (Butler, 2014) in the resulting meat, suggests cattle did receive some cereal based feeds (Kamihiro et al., 2015), with higher levels of supplementation (and hence less forage) on non-organic farms. This is also implied by the relative concentrations of two major trans C18:1 isomers. Rumen microbes in cereal fed cattle favour t10 C18:1 as an intermediate to biohydrogenation, at the expense of VA (t11 C18:1), whereas forage feeding, especially grazing, supports a population producing more VA, which is passed into milk and meat (Vahmani et al., 2020). The ratio of t10:t11 isomers in meat from this study (1.4 for non-organic and 0.4 for organic steak), suggests the latter came from cattle with modest level of cereal supplementation. Whereas it is highly likely both supermarket meats came from cattle fed some concentrate feeds, those producing 'pasture' and 'conservation' steaks were fed 100% forage diets, with the latter having access to *coarser*, more diverse vegetation, possible with fewer grasses and more *browse* species (EnglishNature, 2005).

For many FA (or related traits) thought beneficial for health, we identified a 'gradient' in concentrations (especially in IMF), in-line with assumed intensity of the production systems (as in Fig. 1). However, although values for non-organic (assumed to be the most intensive system) and conservation (the most extensive system) steaks differed significantly, not all intermediated differences reached significance. Even if results for the conservation steaks are ignored due to potential bias from summer slaughtering, many fatty acids show significant differences between non-organic and pasture systems (the next ranked extensive system) - in some cases with the intermediate values for organic also differing from 1 or other or both of these systems.

Fatty acid supply in simulated steak and implications for consumer health

Results confirm lean red meat as a potentially useful supply of n-3, including long chain EPA, DPA and DHA (Scollan et al., 2014; De Smet and Vossen, 2016; Vahmani et al., 2020), to help meet dietary guidelines (European Food Safety Authority 2010) for societies with low consumption of oily fish. To this end, cattle diets dominated with forage (rather than cereals) have been shown to enhance n-3 in meat (Alfaia et al., 2006; Daley et al., 2010) and grass feeding prior to slaughter raises circulating n-3, including LC n-3, for consumers (McAfee et al., 2011). The most striking result from this study is confirmation that steaks from certified 100% pasture feed cattle, for both pasture and conservation systems, qualify as "sources of long chain n-3" under the European Food Standards (European Commission, 2012). If DPA is included in the sum of LC n-3, the mean values for simulated steaks from both systems exceeds the necessary 40 mg long chain n-3 per 100 g food. Research on DPA is more recent than EPA and DHA and it is often overlooked in nutritional guidelines. However, since it is intermediate in the elongation and desaturation pathway between EPA and DHA, has been shown to act as a reservoir for both molecules (Dyall, 2015), and Vahmani et al. (2020) report 37% conversion of DPA to DHA - quantifying its dietary supply ought to be on a par with other LC n-3. In addition to more pre-formed

LC n-3 in pasture and conservation meat, the ratio of LA:ALA and n6:n-3 were significantly lower than other systems, despite differences for ALA, n-3 and n-6 supply not reaching significance. Mean ratios of n-6:n-3 for all systems were within the recognised target range of 2 - 4 x n-6 for 1 of n-3 suggested by Simopoulos (2002). However, this range relates to whole diets and individual foods below this will redress the overall dietary balance down towards the target, as shown with the modelling example of dietary switch to GrassMilk in USA (Benbrook et al., 2018). Also, whereas the importance of the ratio for total n-6:n-3 with respect to cardiovascular health has been questioned, the relative dietary supply of its main components (LA and ALA) are recognised as being highly relevant in the conversion of ALA to longer chain n-3 (Griffin, 2008). In this respect, conservation steak supplied less than 2 units of LA for every one of ALA, compared with over 5:1 for non-organic steak. The less intensive production systems not only supply more pre-formed long chain n-3 than standard steaks but this lower ratio of LA:ALA is likely to enhance consumers' endogenous LC n-3 synthesis from ALA.

A similar situation was found when considering the relative supply of SFA and PUFA in the various steaks. Again, differences in SFA and PUFA *per se* were not significant but the combined effect of less SFA and more PUFA in extensive meat, results in the significant differences in their ratios, with low values for pasture and conservation steaks. Ratios of 5.8:1 and 5.6:1 respectively are substantially lower than the typical values reported for beef of 9–10:1 (Wood et al., 2008; Scollan et al., 2014) or the 8.1:1 and 8.4:1 found for the non-organic and organic steaks here. The higher proportions of polyunsaturated fatty acids in these steaks (7% of total FA supplied in pasture steaks and a very high 11% of total, in the conservation meat, compared with a more typical 5% in the supermarket steak) appears to be at the expense of lower MUFA. The relative proportion of SFA supplied in steaks was fairly consistent across all 4 systems at 43–45% of total, whereas MUFA represented 50 & 51% in the supermarket steak but only 48 & 45% of total FA in the farm sourced meat.

Hints at lipid metabolism in muscle and adipose tissue

Differences between production systems for fatty acid profiles were even stronger when considering their relative concentrations in IMF and SCF, many identified as highly significant. Expressing FA concentrations relative to each other, as a proportion of total FA rather than finite supply, nullifies the direct effect of the variable lipid content of the steaks, influencing the results discussed above.

The likely impact of animal feeding on meat quality is depicted by the incremental increase or decrease in concentration of key FA, following the assumed feeding intensity in production systems. In this study, this is particularly marked for results in IMF. The fatty acid profile in the meat not only suggests a better nutritional balance for consumers but possibly also for cattle on forage diets. Almost without exception the fatty acids we need to increase in our diets were found at higher concentrations in the IMF from conservation and pasture samples, followed by organic and then non-organic meat. This applied to ALA, EPA, n-3 and LC n-3 as well as VA and CLA9, with the opposite pattern for PA, OA as well as the ratios of LA:ALA and n-6:n-3. Perhaps this is not surprising since we know LA supply increases, and ALA decreases in line with the inclusion of cereals in cattle diets, as they replace forage feeds (Butler, 2014). This substitution of ALA with LA supply on intensive diets not only reduces the substrate for cattle to synthesise EPA, DPA and DPA but also introduces greater competition from LA for the enzyme systems involved, resulting in lower levels of LC n-3 available for tissue deposition. The same applies to production of VA by rumen microbes from forage diets (especially grazing), acting as a substrate for endogenous CLA9 synthesis in adipose tissue (Scollan et al., 2006), reducing both VA and CLA9 deposition into meat. Results for IMF here confirm both these theories – the lower the assumed intensity of the cattle diets in this study, the higher the tissue deposition of n-3 including LC n-3 as well as VA and CLA9. However, it needs to be noted, whilst IMF concentration of VA and CLA9 appear to follow this gradient, the only

significant difference for CLA9 is between non-organic and conservation meat and, for VA, results for the conservation meat are higher than any other system. The most likely explanation here is the time of year cattle were slaughtered, since grazing and consumption of fresh forage has been shown to enhance both CLA9 and its precursor VA, in milk and meat compared with silage diets (Daley et al., 2010; Kamihiro et al., 2015; Lenighan et al., 2019).

The differences in SCF composition following the same pattern, for or against system intensification, were more limited; VA and LA concentrations in SCF increased with extensification and the ratio of SFA:PUFA declined. Results here confirm low concentrations of most individual and total PUFA in SCF compared to their concentrations in IMF, generally with the exception of CLA9 (Wood et al., 2008; Kamihiro et al., 2015). Perhaps the most noticeable difference identified for the composition of SCF for the 4 production systems was the higher (or perhaps 'less low' is more appropriate) PUFA content in the 'lean' SCF of the pasture and conservation steak (both with ~55% vs. 73% & 77% total FA content of SCF from non-organic and organic results respectively). The PUFA content of the relatively lean subcutaneous fat layer at the edge of pasture and conservation steaks was almost 5% of total FA. Within this layer, LA concentrations were very low (<0.5% total FA, compared with 3.5–5.2% in IMF), questioning the physiological impact these small (yet significant) differences might have, either in cattle or ultimately for the consumer. Concentrations of VA on the other hand were higher in SCF than IMF, especially for steaks from pasture and conservation cattle. Levels in SCF were almost twice those in IMF and appear to be high in steak for the conservation cattle, most likely due to grazing by these cattle prior to slaughter, as reported by Lenighan et al. (2019). As with IMF, ratios of SFA:PUFA increases with intensification – at 9.5:1 the mean value for pasture steak was less than half the 19.8:1 ratio found for non-organic steak. These high concentrations of unsaturated fatty acid and low SFA:PUFA ratio found in the SCF from steaks from pasture fed and conservation reared cattle are considerably lower than previously reported for retail sirloin steaks (Kamihiro et al., 2015) and are possibly not solely down to the lean meat produced by these systems but could be a reflection of the fatty acid profile of the vegetation and conserved forage eaten by these cattle.

So what?

This preliminary study considered differences in beef fat composition from 4 production systems. Previous researchers report marked seasonality in composition differences between systems for ruminant products, especially if feeding varies throughout the year, in the systems compared. Differences were always smaller, not always significant, in winter and much stronger in summer. From this perspective, meat here (with the exception of the conservation meat) was collected at a time of year when cattle feeding in the systems (on silage-based diets rather than grazing) and hence meat composition, might be expected to be at their most similar, rather than say late summer. Yet differences identified here still proved significant, justifying further study to investigate meat composition when feeding in extensive systems is likely to have greater contrast with those for non-organic production systems. During summer in UK, non-organic, pasture-fed and conservation cattle will be grazing, potentially on very different swards. Cattle on many UK non-organic farms also graze in summer but in many cases, concentrate feeding is introduced in late summer as grass quality deteriorates and non-organic meat also comes from permanently housed cattle fed intensive cereal- or silage-based diets. Sampling meat from cattle slaughtered in late summer would be a good follow-on to assess seasonality in meat quality from extensive production and assess its likely impact on consumer health.

Conclusions

These findings reinforce the concept that the nutritional quality of beef is enhanced by extensive production systems. Whilst differences

between non-organic and organic systems are not new, this is the first record of the extra benefit if cattle are fed 100% -forage diets throughout their life. Their meat ought to be recognised as a 'source of long chain n-3', especially relevant for societies with limited fish consumption. In addition, although meat from conservation cattle in this study was not fully comparable with the other systems, results hint at the potential scope for even greater improvement in the nutritional quality of beef offered by cattle growing slowly, grazing diverse vegetation.

There are substantial tracts of land around the world where altitude, topography, soil cover and/or climate make them unsuitable for vegetable production or arable farming - grazing ruminants are the only option for food production. These results suggest meat produced from diverse vegetation in these areas is likely to be of superior nutritional quality with potential health benefits compared to beef from intensive feedlot production.

Together these results provide evidence of another *public good* (in addition to carbon sequestration and enhanced biodiversity) 'alternative' farming offers over intensive beef production and justifying further investigation into nutritional quality of meat from different types of pasture and vegetation.

Author contributions

Gillian Butler: Conceptualization; Data curation; Formal analysis; Funding acquisition; Methodology; Project admin; Resources; Supervision; Validation; Writing - original draft, review & editing. **Ali Mohamed Ali:** Data curation; Formal analysis; Investigation; Methodology; Visualization; Writing - original draft; Writing - review & editing. **Samson Oladokun:** Data curation; Formal analysis; Investigation; Methodology; Visualization; Writing - original draft, review & editing. **Juan Wang:** Formal analysis; Methodology; Supervision. **Hannah Davis:** Data curation; Formal analysis; Methodology; Supervision; Validation; Writing - review & editing.

Declaration of Competing Interest

GB is a member of PFLA but the study was independent, under a DEFRA funded project.

Acknowledgement

Authors are grateful for funding from DEFRA under the European Research Area on Sustainable Animal Production (SusAn ERA-NET), project SCF0211 SusCatt (2017-2020) and HD was in receipt of funding under Newcastle University Doctoral training scheme. We also appreciate the cooperation and patience of farmers supplying the pasture and conservation meat.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at [doi:10.1016/j.fufo.2021.100012](https://doi.org/10.1016/j.fufo.2021.100012).

References

Alfaia, C.M.M., Quaresma, M.A.G., Castro, M.L.F., Martins, S.I.V., Portugal, A.P.V., Fontes, C.M.G.A., Bessa, R.J.B., Prates, J.A.M., 2006. Fatty acid composition, including isomeric profile of conjugated linoleic acid, and cholesterol in Mertolenga-PDO beef. *J. Sci. Food Agric.* 86 (13), 2196–2205.

Benbrook, C.M., Davis, D.R., Heins, B.J., Latif, M.A., Leifert, C., Peterman, L., Butler, G., Faergeman, O., Abel-Caines, S., Baranski, M., 2018. Enhancing the fatty acid profile of milk through forage-based rations, with nutrition modeling of diet outcomes. *Food Sci. Nutr.* 6 (3), 681–700.

Benjamin, S., Prakasan, P., Sreedharan, S., Wright, A.D.G., Spener, F., 2015. Pros and cons of CLA consumption: an insight from clinical evidences. *Nutr. Metab.* 12 (1).

Butler, G., 2014. Manipulating dietary PUFA in animal feed: implications for human health. *Proc. Nutr. Soc.* 73 (1), 87–95.

Butler, G., Nielsen, J.H., Larsen, M.K., Rehberger, B., Stergiadis, S., Canever, A., Leifert, C., 2011. The effects of dairy management and processing on quality characteristics of milk and dairy products. *NJAS Wageningen. J. Life Sci.* 58 (3–4), 97–102.

Butler, G., Nielsen, J.H., Slots, T., Seal, C., Eyre, M.D., Sanderson, R., Leifert, C., 2008. Fatty acid and fat-soluble antioxidant concentrations in milk from high- and low-input conventional and organic systems: seasonal variation. *J. Sci. Food Agric.* 88 (8), 1431–1441.

Calder, P.C., 2018. Very long-chain n-3 fatty acids and human health: fact, fiction and the future. *Proc. Nutr. Soc.* 77 (1), 52–72.

Conant, R.T., Paustian, K., Elliott, E.T., 2001. Grassland management and conversion into grassland: effects on soil carbon. *Ecol. Appl.* 11 (2), 343–355.

Crawley, M.J., 2007. *The R Book*. John Wiley & Sons, Chichester.

Daley, C.A., Abbott, A., Doyle, P.S., Nader, G.A., Larson, S., 2010. A review of fatty acid profiles and antioxidant content in grass-fed and grain-fed beef. *Nutr. J.* 9 (1).

Davis, H., Chatzidimitriou, E., Leifert, C., Butler, G., 2020. Evidence that forage-fed cows can enhance milk quality. *Sustain. Switz.* 12 (9).

De Smet, S., Vossen, E., 2016. Meat: the balance between nutrition and health. A review. *Meat Sci.* 120, 145–156.

Doreau, M., Bauchart, D., Chilliard, Y., 2011. Enhancing fatty acid composition of milk and meat through animal feeding. *Anim. Prod. Sci.* 51 (1), 19–29.

Dyall, S.C., 2015. Long-chain omega-3 fatty acids and the brain: a review of the independent and shared effects of EPA, DPA and DHA. *Front. Aging Neurosci.* 7 (APR).

EnglishNature, 2005. *The Importance of Livestock Grazing for Wildlife Conservation*. Natural England, Peterborough, UK.

European Food Safety Authority, 2010. *Scientific Opinion on Dietary Reference Values for fats, including saturated fatty acids, polyunsaturated fatty acids, monounsaturated fatty acids, trans fatty acids, and cholesterol*. EFSA J. 8 (3).

EuropeanCommission. *Nutrition and health claims* Retrieved July 2020, from https://ec.europa.eu/food/safety/labelling_nutrition/claims/nutrition_claims_en.

FAO, 2012. *Sustainable Diets and Biodiversity*. FAO, Rome.

Griffin, B.A., 2008. How relevant is the ratio of dietary n-6 to n-3 polyunsaturated fatty acids to cardiovascular disease risk? Evidence from the OPTILIP study. *Curr. Opin. Lipidol.* 19 (1), 57–62.

Hackmann, T.J., Spain, J.N., 2010. Invited review: ruminant ecology and evolution: perspectives useful to ruminant livestock research and production. *J. Dairy Sci.* 93 (4), 1320–1334.

Janis, C.M., Damuth, J., Theodor, J.M., 2002. The origins and evolution of the North American grassland biome: the story from the hoofed mammals. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 177 (1–2), 183–198.

Kamihiro, S., Stergiadis, S., Leifert, C., Eyre, M.D., Butler, G., 2015. Meat quality and health implications of organic and conventional beef production. *Meat Sci.* 100, 306–318.

Lenighan, Y.M., Nugent, A.P., Moloney, A.P., Monahan, F.J., Walton, J., Flynn, A., Roche, H.M., McNulty, B.A., 2019. A Modelling Approach to Investigate the Impact of Consumption of Three Different Beef Compositions on Human Dietary Fat Intakes. *Public Health Nutrition*.

McAfee, A.J., McSorley, E.M., Cuskelly, G.J., Fearon, A.M., Moss, B.W., Beattie, J.A.M., Wallace, J.M.W., Bonham, M.P., Strain, J.J., 2011. Red meat from animals offered a grass diet increases plasma and platelet n-3 PUFA in healthy consumers. *Br. J. Nutr.* 105 (1), 80–89.

McDonald, P.E., A; Greenhalgh, J.F.D.; Morgan, C.A. (2002). *Animal nutrition*. Harlow, UK, Prentice Hall.

Pasture-for-Life. *Certification standards for ruminant livestock*. Retrieved January 2019, from <https://www.pastureforlife.org/media/2014/03/PFLA-standards.pdf>.

Peters, C.J., Picardy, J., Darrouzet-Nardi, A.F., Wilkins, J.L., Griffin, T.S., Fick, G.W., 2016. Carrying capacity of U.S. agricultural land: ten diet scenarios. *Elementa* 2016.

Pinheiro, J.B., D. DebRoy, S. Sarkar, D.R. Core Team, (2017). {nlme}: Linear and nonlinear mixed effects models.

R. Development Core Team, 2009. *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria Version 2.11.1 (2010-05-31).

Rudolph, G., Hörtenhuber, S., Boichicchio, D., Butler, G., Brandhofer, R., Dippel, S., Dourmad, J.Y., Edwards, S., Früh, B., Meier, M., Prunier, A., Winckler, C., Zollitsch, W., Leeb, C., 2018. Effect of three husbandry systems on environmental impact of organic pigs. *Sustain. Switz.* 10 (10).

Scollan, N., Hocquette, J.F., Nuernberg, K., Dannenberger, D., Richardson, I., Moloney, A., 2006. Innovations in beef production systems that enhance the nutritional and health value of beef lipids and their relationship with meat quality. *Meat Sci.* 74 (1), 17–33.

Scollan, N.D., Dannenberger, D., Nuernberg, K., Richardson, I., MacKintosh, S., Hocquette, J.F., Moloney, A.P., 2014. Enhancing the nutritional and health value of beef lipids and their relationship with meat quality. *Meat Sci.* 97 (3), 384–394.

Simopoulos, A.P., 2002. The importance of the ratio of omega-6/omega-3 essential fatty acids. *Biomed. Pharmacother.* 56 (8), 365–379.

Średnicka-Tober, D., Barański, M., Seal, C., Sanderson, R., Benbrook, C., Steinshamn, H., Gromadzka-Ostrowska, J., Rembiałkowska, E., Skwarło-Sońta, K., Eyre, M., Cozzi, G., Krogh Larsen, M., Jordon, T., Niggli, U., Sakowski, T., Calder, P.C., Burdge, G.C., Sotiraki, S., Stefanakis, A., Yolcu, H., Stergiadis, S., Chatzidimitriou, E., Butler, G., Stewart, G., Leifert, C., 2016a. Composition differences between organic and conventional meat: a systematic literature review and meta-analysis. *Br. J. Nutr.* 115 (6), 994–1011.

Średnicka-Tober, D., Barański, M., Seal, C.J., Sanderson, R., Benbrook, C., Steinshamn, H., Gromadzka-Ostrowska, J., Rembiałkowska, E., Skwarło-Sońta, K., Eyre, M., Cozzi, G., Larsen, M.K., Jordon, T., Niggli, U., Sakowski, T., Calder, P.C., Burdge, G.C., Sotiraki, S., Stefanakis, A., Stergiadis, S., Yolcu, H., Chatzidimitriou, E., Butler, G., Stewart, G., Leifert, C., 2016b. Higher PUFA and n-3 PUFA, conjugated linoleic acid, α -tocopherol and iron, but lower iodine and selenium concentrations in organic milk: a systematic literature review and meta- and redundancy analyses. *Br. J. Nutr.* 115 (6), 1043–1060.

- Stampa, E., Schipmann-Schwarze, C., Hamm, U., 2020. Consumer perceptions, preferences, and behavior regarding pasture-raised livestock products: a review. *Food Qual. Prefer.* 82.
- Stanley, P.L., Rowntree, J.E., Beede, D.K., DeLonge, M.S., Hamm, M.W., 2018. Impacts of soil carbon sequestration on life cycle greenhouse gas emissions in Midwestern USA beef finishing systems. *Agric. Syst.* 162, 249–258.
- Stergiadis, S., Leifert, C., Seal, C.J., Eyre, M.D., Nielsen, J.H., Larsen, M.K., Slots, T., Steinhilber, H., Butler, G., 2012. Effect of feeding intensity and milking system on nutritionally relevant milk components in dairy farming systems in the north east of England. *J. Agric. Food Chem.* 60 (29), 7270–7281.
- Tallowin, J.R.B., Rook, A.J., Rutter, S.M., 2005. Impact of grazing management on biodiversity of grasslands. *Animal Sci.* 81 (2), 193–198.
- Turpeinen, A.M., Mutanen, M., Aro, A., Salminen, I., Basu, S., Palmquist, D.L., Grinari, J.M., 2002. Bioconversion of vaccenic acid to conjugated linoleic acid in humans. *Am. J. Clin. Nutr.* 76 (3), 504–510.
- Vahmani, P., Ponnampalam, E.N., Kraft, J., Mapiye, C., Bermingham, E.N., Watkins, P.J., Proctor, S.D., Dugan, M.E.R., 2020. Bioactivity and health effects of ruminant meat lipids. *Invited Review. Meat Sci.* 165.
- Verain, M.C.D., Bartels, J., Dagevos, H., Sijtsema, S.J., Onwezen, M.C., Antonides, G., 2012. Segments of sustainable food consumers: a literature review. *Int. J. Consum. Stud.* 36 (2), 123–132.
- Wahle, K.W.J., Heys, S.D., Rotondo, D., 2004. Conjugated linoleic acids: are they beneficial or detrimental to health? *Prog. Lipid Res.* 43 (6), 553–587.
- Wolmarans, P., 2009. Background paper on global trends in food production, intake and composition. *Ann. Nutr. Metab.* 55 (1–3), 244–272.
- Wood, J.D., Enser, M., Fisher, A.V., Nute, G.R., Sheard, P.R., Richardson, R.L., Hughes, S.I., Whittington, F.M., 2008. Fat deposition, fatty acid composition and meat quality: a review. *Meat Sci.* 78 (4), 343–358.