Animal 16 (2022) 100375

Contents lists available at ScienceDirect

Animal

The international journal of animal biosciences

A quantitative review of on-farm feeding practices to enhance the quality of grassland-based ruminant dairy and meat products

A. Cabiddu [a], G. Peratoner [b], B. Valenti [c], V. Monteils [d], B. Martin [d], M. Coppa [d,*]

[a] Agris Sardegna, Loc. Bonassai 07040, Olmedo, Italy
[b] Laimburg Research Centre, Research Area Mountain Agriculture, Vadena/Pfatten, 39040 Ora/Auer (BZ), Italy
[c] Department of Agricultural, Food and Environmental Sciences (DSA3), University of Perugia, Borgo XX Giugno, 74, 06121 Perugia, Italy
[d] Université Clermont Auvergne, INRAE, VetAgro Sup, UMR1213 Herbivores, 63122 Saint-Genès-Champanelle, France

ARTICLE INFO

Article history:
Received 15 February 2021
Revised 27 August 2021
Accepted 1 September 2021
Available online 28 October 2021

Keywords:
Carotenoids
Colour
Fatty acids
Sensory properties
Terpenoids

ABSTRACT

In the last decades, a large body of evidence has highlighted the major role of feeding management practices in improving specific nutritional, technological and sensory quality traits of ruminant products. However, results have been mostly obtained under controlled conditions, and have been rarely validated on-farm. Therefore, a quantitative review was conducted to quantify the effects of on-farm feeding management practices on carotenoids, fat-soluble vitamins, colour, fatty acids (**FAs**), terpenes and sensory properties in the main animal product categories (**PCs**): dairy products from cattle (**DC**), sheep (**DS**) and goat (**DG**), and meat from cattle (**MC**) and sheep (**MS**). Four feeding scenarios were selected according to the consistency of on-farm studies in the literature: (a) feeding "Fresh herbage" instead of conserved forages; (b) ban any form of silage ("Silage-free"); (c) ban maize silage ("Maize silage-free"); (d) feeding forages from permanent grasslands rich in species or plant secondary metabolites (**PSMs**) ("PSM-rich permanent grassland"). Feeding fresh herbage increased the concentration of carotenoids, fat-soluble vitamin, n-3 FA, rumenic acid, and branched chain FA (**BCFA**), and reduced the concentration of saturated FA, for all PC, with overall stronger effect for dairy products than for meat. The texture of meat and dairy products was marginally affected, whereas feeding fresh herbage decreased lactic and increased vegetal notes in DC. The "Silage-free" feeding scenario resulted in increased vaccenic acid, rumenic acid, BCFA, and C18:3n-3 in DC. The "Maize silage-free" feeding scenario lowered n-6 FA whereas increased n-3, rumenic acid and BCFA concentrations in DC. Feeding ruminants with forages from "PSM-rich permanent grasslands" increased monounsaturated FA, n-3 FA and rumenic acid and decreased n-6 FA in dairy products, and only marginally affected meat FA composition. The DC from "PSM-rich permanent grasslands" showed higher intense, spicy and animal notes. Overall, the differences between feeding management practices observed on farm were smaller than those observed under controlled trials. Several confounding factors, not controlled when operating under on-farm conditions, could be at the origin of these divergences (i.e. mixed diets, forage characteristics, animal-related factors). This review confirmed that farming practices may differently affect several quality traits of ruminant products. It also highlighted the uneven knowledge on the effect of feeding management depending on the PC: larger for milk than for meat and decreasing when moving from cattle to sheep and from sheep to goat.

Implications

Feeding management practices are the most impacting factors to improve nutritional, technological and sensory quality of ruminant products in controlled experiments. However, most studies were conducted under controlled conditions. This review aims at quantifying these effects of feeding management on farm. We identified common feeding management practices able to enhance the quality of cattle and small ruminant meat and dairy products. Factors weakening the expected effects on quality traits on farm were highlighted. This review provides sound information to the stakeholders of ruminant production chains for implementing effective feeding management practices to achieve the targeted quality of ruminant products.

Introduction

Globally, consumers are increasingly demanding for animal products with a high safety standard, nutritional value, and

---

* Corresponding author.
E-mail address: mauro.coppa@inrae.fr (M. Coppa).

https://doi.org/10.1016/j.animal.2021.100375

sensory quality, which are, at the same time, obtained through environment- and animal-friendly practices. To achieve these goals, feeding management is one of the most effective strategies (Prache et al., 2020; Cabiddu et al. 2019; Minchin et al., 2010). By feeding herbage to ruminants (particularly when grazed), dairy and meat products with specific traits are produced. They are rich in carotenoids, vitamins A and E (Nozière et al., 2006; Prache et al., 2020), volatile organic compounds (**VOCs**), and fatty acids (**FAs**) favourable for human nutrition [e.g. monounsaturated FAs (**MUFA**), polyunsaturated FAs (**PUFA**), and n-3 FA] (Coppa et al., 2019; Cabiddu et al., 2019; Scerra et al., 2011), and have specific sensory characteristics, preferred by consumers (Martin et al., 2005). For some products, however, the opposite is true. For instance, certain maize silage and concentrate-based dairy products, such as butter, have been historically preferred for their firmness because of the high melting point of fats therein [due to the richness in saturated FAs (**SFA**)], as this makes them easy to be transported and commercialised even far from the production area (Prache et al., 2020). Similarly, the U.S. population prefers the sensory characteristics of grain-finished animals (Gwin, 2009).

Most feeding strategies that improve the quality of animal products have been tested under controlled conditions (Ferlay et al., 2006; Hurtaud et al., 2009 for dairy products from cattle; Cabiddu et al. 2019 for dairy products from small ruminant; Fraser et al., 2009; and Luciano et al., 2009 for meat). However, under on-farm conditions, other uncontrolled and unstandardised factors (e.g. forage characteristics, animal status, feeding behaviour, and farm management, among others) may interact and thus amplify, confound, or overrule the effects of the employed practices, ultimately affecting the product quality in controlled trials.

Furthermore, most studies focused on one or a few specific quality traits of certain products. To the best of our knowledge, a quantitative review underlining the common effects of on-farm management practices on the quality of ruminant-derived products (meat and dairy) is lacking. Such an approach is highly relevant for the selection of effective management practices to be included in the specification of quality-labelled animal products.

To this end, the aim of the present quantitative review was to elucidate the effects of specific management practices on the quality traits of animal products, focusing exclusively on experiments conducted under on-farm conditions, and to identify which factors effective under controlled conditions remain effective on-farm and to what extent. Furthermore, common management practices that can enhance the quality of grassland-based meat and dairy products derived from cattle and small ruminants are identified. Finally, possible factors explaining the differences in the degree of effect of feeding management on qualitative traits between controlled trials and on-farm studies are discussed.

Material and methods

Data collection and selection of quality traits

Scientific publications were identified through an initial search of literature in the Web of Knowledge and Scopus databases using several search keywords related to the effect of farm management practices on different quality traits of animal products (i.e. pasture*, fresh herbage*, silage*, maize*, hay*, and biodiversity*). Animal species, animal product type, and each quality trait were used as the keywords. Experiments performed under controlled conditions or on experimental farms were excluded, but those reporting data from commercial farms were selected. The data on animal product quality traits and farming practices were collected from peer-reviewed papers and conference proceedings that were published between 1996 and 2019, included proper statistical analyses, and reported probability values for the investigated factors. Only studies that provided detailed information on the proportion of feedstuff on a DM basis and in which at least two farming practices were compared were included. A complete list of the included studies is provided in the supplementary material. A total of 98 studies were included, 70 of which were on dairy products and 28 on meat products; 45 studies dealt with cattle, 12 with goat, and 41 with sheep. There was no study on goat meat. Five product categories (**PCs**) were defined by combining the animal product type and species: dairy cattle (**DC**), dairy goats (**DG**), dairy sheep (**DS**), meat cattle (**MC**), and meat sheep (**MS**). Quality traits having an interest for human nutrition and health or with an effect on the sensory profile of animal products were evaluated, as well as the sensory profile itself. In particular, fat-soluble vitamins and carotenoids were considered due to the antioxidant potential for humans and their influence on dairy product colour (Nozière et al., 2006). The MUFA, PUFA, C18:1cis9, C18:3n-3 (the main n-3 FA in animal products) and its ratio to C18:2n-6 (the main n-6 FA in animal products), branched chain FA (**BCFA**), rumenic acid (CLAcis9trans11) and its precursor C18:1trans11 were included because of their potential positive effect on human health (potential contribution to the prevention against cardiovascular diseases, cancer, obesity, etc.) (Givens, 2010). The effect positive or negative effect of SFA and C18:2n-6 on human health is still in debate: i.e. Hooper et al., (2020) showed that a reduction in SFA intake could help to prevent cardiovascular diseases, but Astrup et al., (2020) highlighted that the intake of SFA form whole fat dairy and unprocessed meat is not associated with increased risk of cardiovascular diseases. Some FAs (SFA, MUFA, PUFA, C18:1cis9/C16:0) affect the fat melting point with consequences on the texture of animal products. Moreover, PUFA can contribute to develop odour-active compounds through oxidation (Martin et al., 2005). Mono-, sesqui-, and total terpenes can potentially play a role on sensory profile as odour-active compounds (Martin et al., 2005). Both instrumentally measured sensory traits, such as colour and texture, pH at 24 h (only for meat), and those evaluated by panel tests (colour, appearance, texture, odour, flavour, and taste) were considered. Only quality traits for which data from at least three publications in a feeding scenario were available were included in the statistical analysis. Several other quality traits were also found in the literature (i.e. other FA, single terpenes, total antioxidant capacity, muscle water holding capacity and microstructure, and cheese granular texture), but the available data were limited to yield reliable statistics; thus, such traits were not considered in the present review. As sensory attributes are often specific to a product (particularly dairy products), they were grouped under sensory families, as described by Piccinali (2012), based on odour, flavour, and taste: intensity, spicy, lactic (acid, milk, yoghurt, cream, fermented cream, and butter), fruity (hazelnut), vegetal (grassy, boiled vegetables, garlic, and onion), brown (caramel, smoked, sweet, and vanilla), animal (animal, stable, barn, and manure), and others (salty, bitter, silage, mould, mothball, and cheese mite). Data on floral and spicy sensory families were limited. Furthermore, texture properties (firm and elastic), including meat tenderness, fattiness, juiciness, and visually estimated intramuscular fat, were considered.

When quality traits were expressed using different units of measurement in different studies, the data were converted to a common unit [mg/kg DM to mg/kg fat for fat-soluble vitamins, g/100 g milk or g/100 g DM to g/100 g FA for FA, 10^6 arbitrary area unit to ln (natural logarithm) of arbitrary area unit for terpenes, and 0-n to a 0–10 scale for sensory descriptors].

Selection of management practices

As most studies focused on specific feeding practices, a common ground for analysis was achieved by grouping them under four main feeding scenarios. The %DM of feedstuffs in the diet, representing the explanatory variables for the quantified effect, was also recorded.

The collected data were attributed to the following main feeding scenarios:

1. Inclusion of fresh herbage in the diet instead of feeding conserved forage and/or concentrates (*fresh herbage*)
2. Renunciation to feed any form of silages in conserved forage- or pasture-based systems during the winter period (but approval to feed hay) (*silage-free*)
3. Renunciation to feed maize silage, including the winter periods in pasture-based systems, but approval to feed grass silage (*maize silage-free*)
4. Use of forages from permanent grasslands rich in species or plant secondary metabolites (PSMs) instead of temporary grasslands dominated by grasses or poor in PSM (*PSM-rich permanent grasslands*).

Each main feeding scenario was analysed with the aim of quantifying the effects of feeding practices. Similarities and differences in effects for cattle and small ruminant meat or dairy products between controlled and on-farm conditions as well as possible confounding factors under on-farm conditions were highlighted.

Statistical analysis

For each study included in the statistical analysis, the mean across replicates, years, and other factors not addressed in the present review were computed for each feeding practice and considered a statistical unit. To evaluate the significance and extent of effect of the most frequent feeding scenario (inclusion of fresh herbage in the diet instead of feeding conserved forage and/or concentrates), a paired sample *t*-test was performed for each quality trait within each PC. When the paired sample *t*-test detected significant differences in a quality trait within a PC, the percent relative change (Δ%) for each data pair was calculated as follows:

$$\Delta\% = \frac{X1 - X0}{X0} \times 100$$

where $X0$ is the reference value and $X1$ is the value to be compared with $X0$.

Then, general linear model analysis was performed, considering the respective DM Δ% of fresh herbage in the diet as a covariate. PCs and their interaction with the covariate were included as the fixed effects to estimate the differences among PCs and detect various responses to the corresponding feeding practice. Considering the great variability of experimental conditions in different studies included, eight or more cases were considered the minimum number for each PC to be included in the general linear model analysis. Bonferroni posthoc test was performed to analyse differences between PCs and their interactions with the covariate (respective DM Δ% of fresh herbage in the diet). For other main feeding scenarios, sufficient data were not available to perform the same analysis. All the statistical analyses were performed using Minitab v. 14.1 (Minitab Inc., State College, PA, USA).

Results and discussion

Structure of the dataset

Among all farming practices considered in this review, the effect of fresh herbage inclusion in animal diets was the most studied under on-farm conditions, but the number of available data varied according to the PCs and quality traits considered. Overall, DC was the most studied category (40 studies), followed by MS and DS (22 and 18 studies, respectively). However, there were a few studies on DG (12 studies) and very few on MC (5 studies); there was no study on goat meat. Furthermore, the studies assessed the effects of feeding hay instead of silage or grass silage instead of maize silage under on-farm conditions on DC alone, and studies on other PCs were lacking. Moreover, the studies assessed the effects of pasture plant diversity under on-farm conditions on DC, DS, and MS alone. Furthermore, among the various quality traits, major FA composition of dairy and meat products was the most widely studied for all farming management practices analysed (61 studies), followed by colour and carotenoids (18 studies), sensory characteristics (11 studies), and total terpene content (7 studies).

The fresh herbage proportion (%DM) of animal diet in the dataset used to investigate the 'fresh herbage' feeding scenario showed marked differences between the "fresh herbage" and the "conserved forages" groups (Table 1); its average proportion in the fresh herbage group ranged between 61 and 100% within a PC, with a mean paired-sample difference of 54–94%. The fresh herbage proportion of animal diet in the dataset used to test the 'PSM-rich permanent grasslands' feeding scenario was comparable between the high- and low-biodiversity groups, regardless of the PC (85–100%, with a mean paired-sample difference of 1–2%; Table 1). Regarding the 'silage-free' feeding scenario, the proportion (%DM) of hay in dairy cattle diet was 61 ± 21.3% (average ± SD; range: 41–100%) and 8 ± 8.1% (range: 0–28%) in the hay and silage groups, respectively, with a paired-sample difference of 53 ± 24.0% (range: 25–100%). In the 'maize silage-free' feeding scenario, the grass silage proportion (%DM) of dairy cattle diet was 48 ± 12.4% (range 31–61%) and 6 ± 7.3% (range: 0–18%) in the grass silage and maize silage groups, respectively, with a paired-sample difference of 46 ± 12.4% (range 31–91%). Conversely, the maize silage proportion (%DM) was 1 ± 1.9 % (range 0–4%) and 49 ± 12.7% (range 39–60%) in the grass silage and maize silage groups, respectively, with a paired-sample difference of 49 ± 14.8% (range 39–59%).

Fresh herbage vs. conserved forage and concentrates

Carotenoids and colour

A fresh herbage-containing diet increased the content of all carotenoids in dairy and meat products (except retinol content in DC) compared with the conserved forage (Table 2). This may be because carotenoids in herbage are photodegraded during forage harvesting and drying (Nozière et al., 2006). For DC, Δ% was +30% for α-tocopherol, +41% for β-carotene, +45% for zeaxanthin, and +63% for lutein. The α-tocopherol and β-carotene content increased by respectively 0.9 and 1.8% per unit increase in the fresh herbage proportion of animal diet (R^2 = 0.67 and 0.82, respectively; Table 3). The extent of these differences is consistent with the findings of controlled trials (Nozière et al., 2006; Prache et al., 2020). For DG, a similar increase was noted for retinol content and a much larger increase for α-tocopherol content (approximately +480%). This may be because only four data sources were available for DG, mostly from studies conducted in Mediterranean shrubby areas, where shrub leaves contain high amounts of α-tocopherol precursors to prevent photooxidative damage in arid environments (Gratani and Varone, 2004). Fresh herbage inclusion in animal diet also increased α-tocopherol content (by 73%) in MS. The lack of difference in retinol content in DC contradicts the increase in its content with fresh herbage inclusion in the diet found in controlled trials (Nozière et al., 2006). However, Chassaing et al. (2016) highlighted the variability in the retinol content of milk in cattle receiving conserved forage on commercial farms. Indeed, grass silage contains more retinol than hay (Nozière et al., 2006).

Table 1
Fresh herbage proportion (%DM) in ruminants' diet according to the feeding scenario within each group.

Including fresh herbage in the diet instead of feeding conserved forage and/or concentrates

Product	Animal species	*n*[1]	Fresh Herbage group[2]	Conserved Forages group[2]	**Paired-sample difference**[2]
Dairy	Cattle	66	61 ± 22.7 (37–100)	8 ± 24.4 (0–45)	54 ± 21.1 (25–100)
	Sheep	50	85 ± 21.1 (32–100)	7 ± 15.5 (0–48)	78 ± 21.2 (30–100)
	Goat	16	79 ± 23.1 (48–100)	0 ± 0 (0–0)	79 ± 17.2 (48–100)
Meat	Cattle	12	66 ± 20.5 (45–100)	0 ± 0 (0–0)	66 ± 20.5 (45–100)
	Sheep	35	100 ± 0.0 (100–100)	6 ± 19.3 (0–40)	94 ± 20.8 (60–100)

Use of forages from permanent grasslands rich in species or PSM[3]

Product	Animal species	*n*[1]	High biodiversity/PSM group[2]	Low biodiversity/PSM group[2]	**Paired-sample difference**[2]
Dairy	Cattle	28	87 ± 24.2 (30–100)	85 ± 17.1 (32–100)	2 ± 1.0 (0–10)
	Sheep	9	100 ± 0.0 (100–100)	100 ± 1.5 (97–100)	1 ± 1.5 (0–3)
Meat	Sheep	14	93 ± 13.2 (70–100)	95 ± 18.3 (50–100)	2 ± 3.8 (0–10)

[1] *n*, number of data.
[2] Average ± SD (minimum–maximum).
[3] PSM, plant secondary metabolites.

Table 2
Effect of feeding fresh herbage instead of conserved forage and/or concentrates on the carotenoids, fat-soluble vitamins, and terpene content, colour and pH of different animal products.

Item	Product	Animal species	*n*[1]	Fresh Herbage group	Conserved Forages group	SEM[2]	Significance[3]
Carotenoids and vitamins (mg/kg fat)							
α-Tocopherol	Dairy	Cattle	20	23.39	17.95	1.458	**
		Goat	3	37.20	6.37	0.306	***
	Meat	Sheep	3	5.88	3.39	0.155	**
Retinol	Dairy	Cattle	7	6.88	5.91	0.977	ns
		Goat	3	9.17	7.20	0.503	*
β-Carotene	Dairy	Cattle	18	6.20	4.40	0.579	**
Lutein	Dairy	Cattle	8	0.67	0.41	0.101	*
Zeaxanthin	Dairy	Cattle	7	0.10	0.07	0.023	†
Terpenes tot (ln arbitrary area unit)	Dairy	Cattle	3	12.48	11.32	2.419	ns
		Sheep	5	18.84	17.88	0.289	*
Monoterpenes tot (ln arbitrary area unit)	Dairy	Cattle	3	11.22	10.34	2.937	†
		Sheep	5	17.99	16.36	0.33	**
Sesquiterpenes tot (ln arbitrary area unit)	Dairy	Cattle	3	11.73	9.67	1.820	ns
		Sheep	5	18.85	10.38	5.170	ns
Colour							
*b**	Dairy	Cattle	9	15.99	14.76	3.134	ns
		Goat	4	2.56	2.14	0.288	*
	Meat	Cattle	4	11.25	10.80	0.318	ns
		Sheep	8	6.38	6.40	1.088	ns
*a**	Dairy	Cattle	9	−1.85	−2.08	0.693	ns
	Meat	Cattle	4	21.95	21.80	0.952	ns
		Sheep	10	13.10	13.24	0.881	ns
*L**	Dairy	Cattle	9	76.30	76.88	2.590	ns
	Meat	Cattle	4	39.30	38.10	0.346	†
		Sheep	10	40.65	42.78	1.429	**
pH 24 h	Meat	Sheep	14	5.72	5.72	0.070	ns

[1] *n*, number of data.
[2] SEM, standard error of the mean; AUU, arbitrary area units.
[3] ***, $P < 0.001$; **, $P < 0.01$; *, $P < 0.05$; †, $P < 0.1$; ns, not significant.

Although carotenoid content is related to colour (Nozière et al., 2006; Luciano et al., 2009), no significant difference in *b**, *a**, or *L** value were found in products derived from animals fed on fresh herbage and conserved forage. The sole exception was the yellower products of grazed DG (+20%). This overall lack of colour differences regardless of significant differences in carotenoid content is unexpected and difficult to explain. This could partially be due to the structure of the dataset. Indeed, carotenoids and colour were extracted by different studies given the lack of studies reporting the results for both. Although correlated, both colour and carotenoid content strongly vary according to the forage type and characteristics (later discussed) (Nozière et al., 2006), inducing high variability and probably concurring to confound the effect under a certain feeding scenario. Furthermore, carotenoids are usually expressed on fat unit, whereas colour is measured on the whole products; different fat or fat on DM contents could have contributed to weaken colour differences.

Terpenoids

A fresh herbage-containing diet increased monoterpene (+10%) and total terpene (+5%) content in DS compared with conserved forage. A similar tendency ($P < 0.1$) was also observed for monoterpenes in DC (+9%). Terpenes are PSM that are particularly abundant in dicots (Mariaca et al., 1997) and can be transferred directly from herbage to milk and then to cheese (Tornambé et al., 2006). Being volatile, some of these compounds are lost during forage harvesting and conservation, resulting in a lower terpene content in dairy products derived from animals fed conserved forage in controlled trials (Croissant et al., 2007; Cabiddu et al., 2019). Thus, it was

Table 3
Effect of the relative increase (Δ%) of fresh herbage proportion in animal diet on the relative variation (Δ%) of the quality traits in different animal products based on fresh herbage compared to conserved forages-based diets.

Item[1]	Product category				Δ% fresh herbage		N[2]	SE[3] model	R^2	Significance (Sign.)[4]		
	Product	Animal species	Intercept (±SE)	Sign.	Covariate coefficient (±SE)	Sign.				Product category	Δ% fresh herbage	Interaction
Carotenoids and vitamins												
α-Tocopherol	Dairy	Cattle	−9.1 (±6.33)	ns	0.9 (±0.14)	***	20	12.37	0.67	nd	***	nd
β-Carotene	Dairy	Cattle	−26.6 (±9.39)	*	1.8 (±0.21)	***	18	18.85	0.82	nd	***	nd
Fatty acids												
C16:0	Dairy	Cattle	−5.4 (±0.99) ^{c}	***	−0.2 (±0.02)	***	42	5.39	0.38	***	***	ns
		Goat	2.5 (±1.39) ^{ab}	ns			10					
		Sheep	−3 (±1.19) ^{bc}	ns			25					
	Meat	Sheep	5.9 (±3.17) ^{a}	**			17					
C18:1trans11	Dairy	Cattle	−22.1 (±11.86)	†	2.1 (±0.22)	***	41	37.78	0.64	ns	***	ns
		Sheep					24					
C18:1cis9	Dairy	Cattle	4.3 (±3.42)	*	0.2 (±0.04)	***	42	8.52	0.38	***	**	ns
		Sheep					25					
C18:2n-6	Dairy	Cattle	1.1 (±4.27)	ns	−0.2 (±0.07)	**	41	15.53	0.12	ns	**	ns
	Meat	Cattle					26					
		Sheep					8					
C18:3n-3	Dairy	Cattle	−8 (±8.58)	ns	1.1 (±0.13)	***	48	35.93	0.42	ns	***	ns
		Goat					10					
		Sheep					26					
	Meat	Cattle					8					
		Sheep					19					
CLAcis9trans11	Dairy	Cattle	0.7 (±14.3)	ns	0.7 (±0.25) ^{a}	*	53	3672	0.65	ns	***	*
		Sheep			0.6 (±0.25) ^{a}	*	26					
	Meat	Cattle			0.2 (±0.13) ^{b}	ns	8					
SFA	Dairy	Cattle	0 (±0.54) ^{a}	ns	−0.1 (±0.01)	***	50	2.94	0.44	**	***	Ns
		Sheep	−2.4 (±0.6) ^{b}	***			25					
	Meat	Cattle	2.4 (±1.65) ^{a}	**			8					
MUFA	Dairy	Cattle	−1.3 (±1.67) ^{b}	ns	0.2 (±0.04)	***	50	9.99	0.32	**	**	ns
		Sheep	7.9 (±1.93) ^{a}	***			24					
	Meat	Sheep	−6.6 (±5) ^{b}	*			11					
PUFA	Dairy	Cattle	−12.4 (±3.99)	**	0.6 (±0.07)	***	50	14.6	0.57	ns	***	ns
		Goat					10					
		Sheep					25					
C18:1cis9/C16:0	Dairy	Cattle	11.1 (±3.98)	*	0.3 (±0.06)	***	47	12.88	0.30	**	***	ns
		Sheep					25					
C18:3n-3/C18:2n-6	Dairy	Cattle	24 (±7.64)	**	2.1 (±0.17)	***	41	39.4	0.65	***	***	ns
		Goat	−35 (±11.41)	**			10					
		Sheep	27.9 (±8.54)	**			26					
	Meat	Cattle	4.9 (±12.6)	ns			8					
		Sheep	−21.9 (±20.77)	*			19					

[1] SFA, sum of straight-chain FA from C4:0 to C24:0, MUFA, sum of monounsaturated FA from C10:1 to C24:1; PUFA, sum of polyunsaturated FA from C18:2 to C22:6.
[2] *n*, number of data.
[3] SE, standard error.
[4] ***, $P < 0.001$; **, $P < 0.01$; *, $P < 0.05$; †, $P < 0.1$; ns, not significant; nd: not determinable.

quite unexpected that neither monoterpenes nor total terpenes in DC and sesquiterpenes in DS were affected by the presence of fresh herbage in the animal diet. This lack of differences, contrary to that observed in controlled trials, could be attributed to several confounding factors, such as forage characteristics (discussed later) and the terpene analytical methods used, which makes it difficult to generalise the differences found in single studies (Abilleira et al., 2010).

Fatty acids

Not all FAs showed significant differences in all PCs (Table 4). Feeding fresh herbage similarly affected the content of several FAs in both dairy and meat products. Specifically, it reduced the content of C16:0 (between −6 and −10%) and SFA (approximately −5%) in dairy products of all studied animals (not significant for SFA in DG) and meat products of sheep (−5 and −6%, respectively) (Table 4). This effect of fresh herbage in animal diets on reducing the C16:0 content of meat and dairy products is well-documented under controlled conditions (Elgersma, 2015; Daley et al., 2010; Sinclair, 2007), although it appears to be stronger than that found in the present study (between −11 and −31% for both in DC) (Ferlay et al., 2006; Cabiddu et al., 2019). C16:0 is partially derived from intake, and its content is low in fresh herbage (Elgersma, 2015). It is also partially synthesised *de novo* in the mammary gland and partially inhibited when high amounts of PUFA are transferred to the mammary gland (Elgersma, 2015). In our study, the C16:0 and SFA content decreased by respectively −0.2 and −0.1% with per unit increase in the fresh herbage proportion of animal diet, regardless of the PC (Table 3).

The BCFA (content) of the products of DC increased when the animals were fed fresh herbage rather than conserved forage (+11%; Table 4). These FAs are derived from ruminal cellulolytic bacteria (Buccioni et al., 2012). In controlled trials (Couvreur et al., 2006; Ferlay et al., 2006), their content in the milk of fresh herbage-fed cattle has been reported to be higher because of the higher cellulose and hemicellulose content and fibre digestibility of fresh herbage than of conserved forage (Couvreur et al., 2006; Ferlay et al., 2006).

Feeding fresh herbage instead of conserved forage increased the C18:1cis9 and MUFA content in DC (+7 and +9%, respectively) and

Table 4
Effect of feeding fresh herbage instead of conserved forage and/or concentrates on the fatty acid profile of different animal products.

Fatty acids (g/100 g FA)[1]	Product	Animal species	*n*[2]	Fresh Herbage group	Conserved Forages group	SEM[3]	Significance[4]
C16:0	Dairy	Cattle	42	28.18	31.28	0.660	***
		Goat	10	26.02	27.67	2.023	**
		Sheep	22	21.45	23.08	0.656	***
	Meat	Cattle	8	24.64	24.99	0.400	ns
		Sheep	17	21.77	23.15	0.677	**
C18:1trans11	Dairy	Cattle	41	2.44	1.30	0.155	***
		Goat	5	1.81	1.22	0.594	ns
		Sheep	21	3.63	2.11	0.337	***
	Meat	Cattle	3	3.94	2.80	0.520	ns
		Sheep	8	1.57	0.99	0.375	*
C18:1cis9	Dairy	Cattle	42	20.79	19.39	0.315	***
		Goat	11	18.10	18.13	1.071	ns
		Sheep	22	19.46	17.20	0.994	**
	Meat	Cattle	4	34.80	34.63	1.687	ns
		Sheep	16	34.46	35.36	1.460	ns
C18:2n-6	Dairy	Cattle	41	1.52	1.77	0.085	***
		Goat	10	2.38	2.30	0.228	ns
		Sheep	23	3.75	4.24	1.014	ns
	Meat	Cattle	8	2.30	2.72	0.488	†
		Sheep	19	6.00	7.29	0.623	*
C18:3n-3	Dairy	Cattle	48	0.81	0.57	0.046	***
		Goat	10	0.68	0.48	0.063	**
		Sheep	23	1.73	1.11	0.177	***
	Meat	Cattle	8	1.00	0.69	0.053	**
		Sheep	19	2.00	1.16	0.176	**
CLAcis9trans11	Dairy	Cattle	53	1.20	0.65	0.707	***
		Goat	6	0.83	0.46	0.225	†
		Sheep	23	2.09	1.08	0.352	**
	Meat	Cattle	8	0.79	0.53	0.046	**
		Sheep	7	0.91	0.75	0.168	ns
SFA	Dairy	Cattle	50	63.78	66.93	0.783	***
		Goat	10	68.42	69.11	3.510	ns
		Sheep	22	61.01	64.30	1.614	**
	Meat	Cattle	8	48.74	49.86	0.651	*
		Sheep	13	45.39	46.24	1.327	ns
MUFA	Dairy	Cattle	50	28.27	26.04	0.393	***
		Goat	10	20.22	20.33	1.186	ns
		Sheep	21	23.35	20.00	1.147	***
	Meat	Cattle	8	44.01	43.51	1.066	ns
		Sheep	11	39.98	37.78	1.701	*
PUFA	Dairy	Cattle	50	4.61	3.78	0.207	***
		Goat	10	4.29	3.68	0.235	*
		Sheep	22	6.31	5.13	0.351	***
	Meat	Cattle	8	6.08	5.55	0.931	ns
		Sheep	15	16.50	17.60	2.107	ns
BCFA	Dairy	Cattle	32	2.34	2.10	0.140	**
C18:1cis9/C16:0	Dairy	Cattle	47	0.77	0.65	0.023	***
		Goat	10	0.73	0.69	0.087	ns
		Sheep	22	0.92	0.75	0.493	***
	Meat	Cattle	4	1.47	1.41	0.070	ns
		Sheep	16	1.61	1.56	0.069	ns
C18:3n-3/C18:2n-6	Dairy	Cattle	41	0.53	0.33	0.036	***
		Goat	10	0.34	0.22	0.036	***
		Sheep	23	0.64	0.37	0.799	***
	Meat	Cattle	8	0.51	0.29	0.050	**
		Sheep	19	0.39	0.18	0.041	***

[1] SFA, sum of straight-chain FA form C4:0 to C24:0, MUFA, sum of monounsaturated FA from C10:1 to C24:1; PUFA, sum of polyunsaturated FA form C18:2 to C22:6, BCFA, sum of branched chain FA from C13:0-iso to C18:0-iso.

[2] *n*, number of data.

[3] SEM, standard error of the mean.

[4] ***, $P < 0.001$; **, $P < 0.01$; *, $P < 0.05$; †, $P < 0.1$; ns, not significant.

DS (+13 and +17%, respectively), but did not affect the content of these FAs in meat, except for MUFA in MS (+6%) (Table 4). The C18:1cis9 content of dairy products and that of MUFA in MS increased linearly by 0.2% with per unit increase in the fresh herbage proportion of diet. A high C18:1cis9 content of animal products is related to fresh herbage intake (Elgersma, 2015). However, this FA is derived from multiple pathways. It can originate from lipid mobilisation or mammary Δ^9-desaturase action (Chilliard et al., 2007). The C18:1cis9/C16:0 ratio increased with the increasing proportion of fresh herbage in DC (+17%) and DS

(+22%); this was expected because of the above-mentioned results of single FAs. Its value increased by 0.3% with per unit increase in the fresh herbage proportion of animal diet. This ratio, also called the spreadability index, is related to the texture and sensory properties of dairy products (Hurtaud et al., 2009; Giaccone et al., 2016; Chilliard et al., 2007).

Furthermore, feeding fresh herbage strongly increased the content of C18:3n-3, the major FA of fresh herbage (Elgersma, 2015), in both dairy and meat products of all species studied (+41 and +73%, respectively) (Table 4). However, it decreased the C18:2n-6 content of dairy (−14% in DC) and meat (between −15 and −18%). The C18:3n-3 content linearly increased by 1.1% with per unit increase in the fresh herbage proportion of animal diet, regardless of the animal product ($R^2 = 0.42$; Table 3). Similar results were observed for C18:2n-6 (−0.2 % per unit increase in the fresh herbage proportion of animal diet), although the model fit was poor ($R^2 = 0.12$; Table 3). The C18:2n-6 is the second major constituent of herbage lipids, but it is also abundant in maize silage and cereal concentrates (Elgersma, 2015). This implies that its content in various products also depends on the type and proportion of conserved forage and concentrate in the diet (Chilliard et al., 2007; Daley et al., 2010; Sinclair, 2007). According to the differences observed for C18:3n-3 and C18:2n-6, their ratio greatly increased (between 52 and 71% in dairy products and between 77 and 124% in meat) when fresh herbage was provided instead of conserved forages (Table 4). This ratio linearly increased by 1.1% with per unit increase in the fresh herbage proportion of animal diet, regardless of the animal products ($R^2 = 0.65$; Table 3). The observed increase in the C18:3n-3 content by feeding fresh herbage-based diets was greater (between 80 and 150%) in controlled trials (Couvreur et al., 2006; Biondi et al., 2008; Daley et al., 2010, Scerra et al., 2011); however, the trend was similar, albeit sometimes not significant, for C18:2n-6 (Couvreur et al. 2006; Khanal et al., 2008), largely depending on the type of conserved forage and concentrate. Compared to that in conserved forage, C18:3n-3 in fresh herbage can be more efficiently transferred to the animal products, as this FA is allocated to the membrane lipids (Buccioni et al., 2012).

The C18:1trans11 and CLAcis9trans11 content increased by respectively 72 and 94% in dairy products with the inclusion of fresh herbage in animal diet (Table 4), consistent with the increase in C18:3n-3 and C18:2n-6 content. In fact, C18:3n-3 and C18:2n-6 are partially biohydrogenated to C18:1trans11 (Buccioni et al., 2012), which is desaturated in the mammary gland to CLAcis9trans11 (Chilliard et al., 2007). Similarly, the C18:1trans11 content was significantly increased in MS (+59%) and the CLAcis9trans11 content was increased in MC (+48%) when the animals were fed fresh herbage. Such increases for both FAs have also been reported in controlled trials, albeit with a greater variability. Ferlay et al. (2006) and Coppa et al. (2015) have reported consistent increases under on-farm conditions, while other studies have reported larger increases (between +150 and +478% for C18:1trans11 and between +177 and +380%, with an extreme of +16% at the lower range, for CLAcis9trans11) (Khanal et al., 2008; Biondi et al., 2008; Daley et al., 2010). The C18:1trans11 content in all PCs linearly increased by 2.1% with per unit increase in the fresh herbage proportion of animal diet ($R^2 = 0.64$; $P < 0.01$, Table 3). The CLAcis9trans11 content showed different increasing trends between dairy and meat products; in the former, it linearly increased by 0.7 and 0.6% with per unit increase in the fresh herbage proportion of cattle and sheep diets, respectively, not differing between dairy product categories, but the slope coefficient of CLAcis9trans11 in MC was not significant (Table 3). This difference in MC could be due to the lower activity of Δ^9-desaturase in the adipose tissue than in the mammary gland (Chilliard et al. 2007) or partially due to the heterogeneity of the dataset in terms of animal age and sex (De La Torre et al., 2005), coupled with a relatively low number (8) of available studies.

The PUFA content in dairy products increased between 17 and 23% with a fresh herbage-based diet (Table 4), whereas no effect was observed for meat. Its content in all dairy products increased by 0.6% with per unit increase in the fresh herbage proportion of animal diet ($R^2 = 0.57$; $P < 0.01$) (Table 3). These results are consistent with those of controlled trials on cattle (Chilliard et al. 2007) and goats (Mancilla-Leytón et al., 2013), although controversial results have been reported for DS, perhaps because of the variability induced by mixed diets, as discussed later (Biondi et al. 2008; Cabiddu et al. 2019). Such an increase of PUFA content in dairy products is relevant both for the sensory properties of milk and cheese and for human nutrition, as an increase in PUFA intake is considered a preventive factor against cardiovascular diseases. High PUFA content in dairy products has been associated to a less firm and more melting texture and to a greater richness in odour-active compounds and sensory descriptors (Hurtaud et al., 2009; Giaccone et al., 2016; Frétin et al., 2019).

Sensory properties

The evaluation of sensory properties of several diverse dairy and meat products is a scientific challenge, as sensory descriptors are often specific to a single product. The choice of grouping specific and heterogeneous sensory descriptors in sensory families implied an increase in the variability of the dataset. This is particularly the case for different cheese types, as the cheesemaking technology employed is one of the most influential factors for the sensory profile of cheese (Martin et al., 2005). Thus, a substantial loss of the significance of the effect of farming practices was expected. However, several sensory families of dairy and meat products were affected by the inclusion of fresh herbage in animal diets (Table 5). This diet tended ($P < 0.1$) to make the meat more elastic in DS (+18%) than conserved forage, which is consistent with the results of the C18:1cis9/C16:0 ratio and MUFA and PUFA content (Martin et al., 2005; Hurtaud et al., 2009; Frétin et al., 2019). Differences in cheese texture between fresh herbage and conserved forage diets and across cheesemaking processes (Martin et al., 2005; Farruggia et al., 2014) have been well-documented in controlled trials. As such, cheese derived from fresh herbage-fed animals is less firm and more elastic and melts more easily. However, the lack of effect on cheese texture under on-farm conditions is not surprising. Cheesemakers can indeed reduce textural variations by adapting curd draining. Conversely, flavour, odour, and taste are more difficult to control, as shown by the differences we observed in these traits under on-farm conditions. In particular, fresh herbage-based diets reduced lactic notes in cheese compared with conserved forage for both DC and DS (−10 and −21%, respectively; Table 5). Under controlled conditions, cheese lactic notes were suppressed with a reduction of fresh herbage proportion of diet in DC and DS (Giaccone et al., 2016; Valdivielso et al., 2016).

Fresh herbage inclusion in diet increased vegetal family notes for DC (+30%). Giaccone et al. (2016) showed that cheese derived from grazing cattle had more pronounced vegetal notes, which may be related to the high unsaturated FA content of cheese. The authors hypothesised that the oxidation of unsaturated FA, which have a low oxidative stability, produces several odour-active compounds during cheese ripening, such as alcohols, esters, aldehydes, and ketones, which are associated with vegetal and herbaceous notes. However, Frétin et al. (2019) have proposed a microbial origin of such flavour differences related to fresh herbage inclusion in cattle diets. Fresh herbage increased animal family notes in MS compared with conserved forage (+12%; Table 5). Fresh herbage increased the indole and skatole content of sheep meat compared with conserved forages (Vasta and Priolo, 2006; Schreurs et al.

Table 5
Effect of feeding fresh herbage instead of conserved forage and/or concentrates on the sensory properties of different animal products.

Item[1]	Product	Animal Species	n[2]	Fresh herbage group	Conserved Forages group	SEM[3]	Significance[4]
Elastic	Dairy	Cattle	4	2.54	2.44	1.120	ns
		Sheep	3	3.40	2.80	0.200	†
Tenderness	Meat	Cattle	5	5.60	5.60	0.231	ns
		Sheep	8	5.56	5.28	0.330	ns
Intensity	Dairy	Cattle	3	3.90	3.27	0.100	ns
		Sheep	3	1.10	0.74	0.150	ns
	Meat	Cattle	4	5.80	5.70	0.577	ns
		Sheep	10	4.75	3.99	0.375	ns
Lactic	Dairy	Cattle	17	3.01	3.34	0.361	*
		Sheep	6	2.22	2.80	0.381	*
	Meat	Sheep	6	3.13	3.72	0.517	ns
Vegetable	Dairy	Cattle	15	3.25	2.51	0.360	***
Brown	Dairy	Cattle	12	2.19	1.71	0.495	ns
Animal	Dairy	Cattle	8	2.64	2.23	0.859	ns
	Meat	Sheep	6	5.12	4.50	0.247	**
Others	Dairy	Cattle	15	3.00	2.65	0.539	†
Fattiness	Meat	Cattle	8	2.02	1.91	0.116	ns
Juiciness	Meat	Cattle	4	5.30	5.20	0.058	ns
		Sheep	8	4.37	4.62	0.465	ns
Intramuscular fat	Meat	Sheep	8	1.94	2.81	0.370	*

[1] Sensory properties were grouped under sensory families, as described by Piccinali (2012), based on odour, flavour, and taste: intensity, lactic (acid, milk, yoghurt, cream, fermented cream, and butter), vegetable (grassy, boiled vegetables, garlic, and onion), "brown" (caramel, smoked, sweet, and vanilla), animal (animal, stable, barn, and manure), and others (salty, bitter, silage, mould, mothball, and cheese mite). Sensory trait data were converted to a common 0–10 scale.
[2] n, number of data.
[3] SEM, standard error of the mean.
[4] ***, $P < 0.001$; **, $P < 0.01$; *, $P < 0.05$; †, $P < 0.1$; ns, not significant.

2007). Skatole is produced by ruminal bacteria-mediated degradation of tryptophan, and its availability increases with a high protein content and high protein/readily digestible carbohydrate ratio, as in fresh herbage-based diet (Vasta and Priolo, 2006).

Intramuscular fat in meat sheep decreased when animals were fed fresh herbage (−31%). A number of intrinsic (age, breed, and sex) and extrinsic factors (pasture quality and physical activity) may contribute to the variation in intramuscular fat deposition (De Brito et al., 2017). According to Gallo et al. (2019), the overall lack of concentrates in diet of grazing sheep reduces the availability of propionate at the ruminal level, which is a precursor of glucose and glycogen at the muscular level. Moreover, enhanced lipid mobilisation due to a lower energy intake may favour lean muscle deposition in grazing animals.

Hay vs. silage

Feeding grass silage instead of hay increased the α-tocopherol content in DC (+10%; Table 6). This may be due to shorter exposure to photodegrading UV light during silage making (Nozière et al., 2006). Furthermore, when herbage is ensiled, it is often harvested at an earlier phenological stage than hay, and the content of α-tocopherol in herbage decreases with herbage maturation, with a pivotal role played by the decreased stem/leaf ratio (Nozière et al., 2006). However, although this decrease was common to all carotenoids, no differences in β-carotene and retinol content were observed between silage and hay. Feeding hay instead of silage increased the content of C18:1trans11 (+19%), CLAcis9trans11 (+18%), and BCFA (+14%), while slightly increasing trends were observed for the C18:3n-3 content and C18:3n-3/C18:2n-6 ratio (+17 and +20%, respectively, both $P < 0.1$) (Table 6). These findings corroborate the results obtained under controlled conditions, although the extent of increase under the controlled conditions was higher (between 22 and 48% for all listed FAs; Ferlay et al., 2006). The FA profile of milk derived from hay-fed animals was consistent with a higher transfer rate of C18:3n-3 from a hay-based than a silage-based diet (Chilliard et al., 2007). In addition, maize silage was poor in C18:3n-3 but rich in C18:2n-6, which differently affected milk FA profiles depending on the type of silage (grass or maize) fed to the animals.

Grass silage vs. maize silage

The α-tocopherol and β-carotene content in DC did not differ between maize silage- and grass silage-based diets (Table 7). Although milk derived from animals fed maize silage-based diets is poor in α-tocopherol (Stergiadis et al., 2015; Botana et al. 2018), maize silage is often not the exclusive conserved forage under on-farm conditions, and grass silage is also present in non-negligible proportions in cattle diet, particularly in intensive farming systems (Stergiadis et al., 2015). Indeed, Botana et al. (2018) showed that diets containing exclusively maize or grass silage as forage led to differences in the vitamin and carotenoid content of milk.

Feeding grass silage instead of maize silage decreased the milk content of C16:0 (−4%; $P < 0.1$) and of C18:2n-6 (−9%) but increased the milk content of C18:3n-3 (+34%), CLAcis9trans11 (+24%; $P < 0.1$), PUFA (+7%), BCFA (+15%) as well as the ratio of C18:3n-3/C18:2n-6 (+39%) in DC. The extent of these changes was consistent with findings obtained under controlled trials (Ferlay et al., 2006; Chilliard et al., 2007; Khanal et al. 2008). Furthermore, maize silage is rich in starch, and a shift in the ruminal population from cellulolytic to amylolytic bacteria reduces the BCFA content of milk (Buccioni et al., 2012).

Permanent grasslands rich in species or in plant secondary metabolites vs. temporary grasslands

Most experiments related to the effects of pasture plant diversity have revealed significant differences in quality traits such as terpenes, FAs, carotenoids, and sensory properties (among others Ferlay et al., 2006; Tornambé et al., 2006; Cabiddu et al., 2019;

Table 6
Effect of feeding hay instead of silage on the quality traits of cattle dairy products.

Item[1]	*n*[2]	Hay group	Silage group	SEM[3]	Significance[4]
Carotenoids and vitamins (mg/kg fat)					
α-Tocopherol	4	9.01	9.91	0.358	*
Retinol	4	5.73	5.84	0.945	ns
β-Carotene	3	2.46	2.65	0.930	ns
Fatty acids (g/100 g FA)					
C16:0	15	31.31	32.11	0.711	ns
C18:1trans11	12	1.23	1.00	0.090	*
C18:1cis9	14	19.10	18.52	0.569	ns
C18:2n-6	15	1.88	1.93	0.153	ns
C18:3n-3	15	0.54	0.45	0.043	†
CLAcis9trans11	15	0.58	0.47	0.032	*
SFA	15	65.95	66.61	2.610	ns
MUFA	15	25.42	25.07	0.714	ns
PUFA	15	3.69	3.49	0.217	ns
BCFA	12	1.83	1.57	0.193	*
C18:1cis9/C16:0	15	0.61	0.59	0.027	ns
C18:3n-3/C18:2n-6	15	0.33	0.26	0.034	†

[1] SFA, sum of straight-chain FA from C4:0 to C24:0; MUFA, sum of monounsaturated FA from C10:1 to C24:1; PUFA, sum of polyunsaturated FA from C18:2 to C22:6, BCFA, sum of branched chain FA from C13:0-iso to C18:0-iso.

[2] *n*, number of data.

[3] SEM, standard error of the mean.

[4] ***, $P < 0.001$; **, $P < 0.01$; *, $P < 0.05$; †, P < 0.1; ns, not significant.

Table 7
Effect of feeding grass silage instead of maize silage on the quality traits of cattle dairy products.

Item[1]	*n*[2]	Grass silage group	Maize silage group	SEM[3]	Significance[4]
Carotenoids and vitamins (mg/kg fat)					
α-Tocopherol	3	14.26	13.98	5.455	ns
β-Carotene	3	6.68	3.11	0.965	ns
Fatty acids (g/100 g FA)					
C16:0	6	32.72	33.96	1.137	†
C18:1trans11	6	1.13	0.93	0.231	ns
C18:1cis9	6	17.80	17.32	0.875	ns
C18:2n-6	7	1.57	1.71	0.161	*
C18:3n-3	7	0.62	0.40	0.050	*
CLAcis9trans11	7	0.54	0.41	0.699	†
SFA	7	69.00	69.92	0.707	ns
MUFA	7	24.71	24.22	1.100	ns
PUFA	7	3.33	3.10	0.240	*
BCFA	5	1.91	1.62	0.287	*
C18:1cis9/C16:0	6	0.55	0.51	0.337	ns
C18:3n-3/C18:2n-6	7	0.41	0.25	0.044	*

[1] SFA, sum of straight-chain FA from C4:0 to C24:0; MUFA, sum of monounsaturated FA from C10:1 to C24:1; PUFA, sum of polyunsaturated FA from C18:2 to C22:6, BCFA, sum of branched chain FA from C13:0-iso to C18:0-iso.

[2] *n*, number of data.

[3] SEM, standard error of the mean.

[4] ***, $P < 0.001$; **, $P < 0.01$; *, $P < 0.05$; †, $P < 0.1$; ns, not significant.

Serrano et al., 2011). However, under on-farm conditions, increasing plant diversity tended to decrease retinol content (−10%; $P < 0.1$) in DC (Table 8). The results for carotenoids are consistent with those for colour.

Similarly, although a number of experimental studies have shown that the terpene content of dairy products was strongly affected by grassland biodiversity (Abilleira et al., 2010; Bovolenta et al. 2014), no difference in terpene content in dairy products was detected depending on the biodiversity of grazed pastures (Table 8).

Grazing on permanent grasslands with a high plant diversity rather than on temporary grassland with a low diversity reduced the C16:0 content in MS (−11%). Sheep operate a remarkable selection of forage plants to meet their nutritive requirements (Villalba et al., 2011). A greater herbage species diversity in permanent grasslands may promote their selective behaviour towards patches with a high nutritive value and abundant PUFA, thus modifying the FA composition of the ingested diet in the favour of PUFA and decreasing the accumulation of *de novo*-synthesised FAs.

The high botanical diversity of pastures decreased the SFA content (−4%) but increased the C18:1trans11 (+10%), C18:1cis9/C16:0 (+13%), C18:2n-6 (+10%), C18:3n-3 (+13%), CLAcis9trans11 (+15%), MUFA (+7%), and PUFA (+13%) content and the C18:3n-3/C18:2n-6 (+6%) ratio in DC. It also increased the C18:2n-6 (+10%), C18:3n-3 (+19%), CLAcis9trans11 (+15%), MUFA (+3%), and PUFA (+15%) content in DS (Table 9). Similar results for these FAs have been reported under controlled conditions, albeit at greater extents (between 29 and 53%; Farruggia et al., 2014; Cabiddu et al., 2019). The high concentration of unsaturated FAs (notably C18:3n-3, C18:2n-6, and their ruminal biohydrogenation intermediates) is consistent with the partial inhibition of ruminal microbial activity by PSMs, which are usually abundant in botanically diverse pasture (Buccioni et al., 2012). Moreover, the greater outflow of PUFA from the rumen as a result of the inhibition of biohydrogenation may have reduced the deposition of C16:0 in MS.

Grazing on pastures with a high plant diversity affected the sensory profile of products in DC by increasing their intensity (+10%), spicy (+100%), and animal (+57%; $P < 0.1$) notes (Table 8). These

Table 8
Effect of feeding forages from permanent grasslands, botanically diversified or rich in plant secondary metabolites (PSMs) instead of temporary grasslands dominated by grasses on the carotenoids, fat-soluble vitamins, and terpene content, colour and sensory properties of different animal products.

Item[1]	Product	Animal species	n[2]	High biodiversity group	Low biodiversity group	SEM[3]	Significance[4]
Carotenoids and vitamins (mg/kg fat)							
α-Tocopherol	Dairy	Cattle	7	13.55	12.35	2.228	ns
Retinol	Dairy	Cattle	5	5.36	5.93	0.488	†
β-Carotene	Dairy	Cattle	7	5.23	3.87	0.919	ns
Terpenes tot (ln arbitrary area unit)	Dairy	Cattle	4	7.62	7.46	1.432	ns
Colour							
b^*	Dairy	Cattle	4	15.79	15.68	4.114	ns
a^*	Dairy	Cattle	4	−1.77	−1.66	1.086	ns
L^*	Dairy	Cattle	4	76.28	77.60	3.169	ns
Sensory properties							
Hardness	Meat	Sheep	4	3.55	3.83	0.144	*
Tenderness	Meat	Sheep	4	6.45	6.10	0.212	ns
Intensity	Dairy	Cattle	4	4.11	3.74	0.094	*
Spicy	Dairy	Cattle	4	4.67	2.23	0.770	*
Animal	Dairy	Cattle	4	4.98	3.18	0.067	†
Others	Dairy	Cattle	6	2.97	2.44	0.453	ns
	Meat	Sheep	10	2.94	2.98	0.484	ns
Fattiness	Meat	Sheep	10	12.93	10.95	3.845	ns
Juiciness	Meat	Sheep	10	13.39	11.36	3.732	ns

[1] Sensory properties were grouped under sensory families, as described by Piccinali (2012), based on odour, flavour, and taste: intensity, spicy (clover, nutmeg, pepper, mint), animal (animal, stable, barn, and manure), and others (salty, bitter, silage, mould, mothball, and cheese mite). Sensory trait data were converted to a common 0–10 scale.

[2] n, number of data.

[3] SEM, standard error of the mean; AUU, arbitrary area units.

[4] ***, $P < 0.001$; **, $P < 0.01$; *, $P < 0.05$; †, $P < 0.1$; ns, not significant.

results are particularly relevant as they corroborate some findings observed in controlled trials (Farruggia et al., 2014; Bovolenta et al. 2014), although the extent of these changes was much larger under on-farm conditions. This can partially be due to the smaller cheese size and shorter ripening period often applied in controlled trials than in practices on commercial farms. Larger size changes the rind–paste ratio and slows microbial dynamics within a wheel. Indeed, cheeses from pastures with a high botanical diversity require longer ripening periods to fully develop their aromatic potential than those from temporary grassland, allowing differentiation in the sensory profile only after a long ripening period (Agabriel et al., 2004; Farruggia et al., 2014).

There is no straightforward explanation for the effects of grassland biodiversity on hardness in MS. Highly diversified grasslands are rich in PSMs, which exhibit strong antioxidant activity (Vasta and Priolo, 2006). Therefore, a greater intake of PSM may protect phospholipids from oxidative damage to a greater extent in the cell membranes in the muscle of sheep grazing on diversified pasture, which may in turn improve water retention. In addition, the difference in hardness could be due to the uneven availability of nutrients in the two types of pasture. In particular, the greater availability of plant species in highly diversified grasslands may enable (or favour) the selection of a more balanced diet in terms of nutrients and allow animals to reach the target slaughtering weight earlier.

Factors weakening the effect of feeding management practices under on-farm conditions

Overall, we found differences in fewer traits between farming practices than did previous controlled trials. Furthermore, the extent of differences observed here under on-farm conditions was generally lower than that under controlled conditions. Indeed, several confounding factors may be acting on farms, increasing variability and thus weakening the differences observed in controlled trials (Bronkema et al., 2019; Coppa et al., 2019).

First, in controlled experiments, well-contrasted diets are usually compared, whereas on-farm, diets are often characterised by other forage components at a minor proportion relative to the dominant one (Coppa et al., 2019; Biondi et al., 2008; Monteils and Sibra, 2019). In particular, this may explain the lack of differences in the retinol content of milk of animals fed fresh herbage or conserved forage, as mineral supplements or concentrates, often enriched in vitamin A, may be added to such diets (Nozière et al., 2006). The same may be true for the FA composition between hay- and silage-based diets, as different proportions of grass or maize silage may be included in the animal diets (Ferlay et al., 2006; Hurtaud et al., 2009; Chilliard et al., 2007; Minchin et al., 2010). In addition, the level and type of concentrate supplementation may have weakened the differences in the quality traits between the addressed practices within each feeding management scenario (Chilliard et al., 2007; Minchin et al., 2010).

Second, the characteristics of forage fed to animals, particularly of fresh herbage, can significantly affect the extent of differences expected on the quality traits. Advanced phenological stages of herbage decreased the content of C18:1trans 11, CLAcis9trans11, and C18:3n-3 but increased the content of C16:0 in milk (Coppa et al., 2015; Cabiddu et al., 2019). The herbage and milk terpene content increased from the vegetative to flowering stage (Tornambé et al., 2006; Cabiddu et al., 2019), probably affecting the differences expected at the pasture biodiversity level. In addition, grazing selection by animals (Coppa et al., 2011; Coppa et al., 2015; Molle et al. 2017) may be considered a confounding factor, as it can change according to pasture botanical composition, plant morphology, maturity stage, slope, and grazing management (Coppa et al., 2011; Cabiddu et al., 2017). Under the availability of numerous species at different phenological stages, ruminants are expected to preferably select plants at an earlier developmental stage, which contain low levels of PSMs. Restriction of selection in grazing pastures with a high plant diversity increased the milk monoterpene content by up to 200% (Tornambé et al., 2006). Similarly, the milk SFA content changed by approximately 10% from the beginning to the end of a paddock (Coppa et al., 2015). Plant composition can also significantly affect the extent of differences expected in carotenoid and fat-soluble vitamin content of cattle milk (Bovolenta et al. 2014), as legumes usually have a lower α-

Table 9
Effect of feeding forages from permanent grasslands, botanically diversified or rich in plant secondary metabolites (PSMs) instead of temporary grasslands dominated by grasses on the fatty acid profile of different animal products.

Fatty acids (g/100 g FA)[1]	Product	Animal species	*n*[2]	High biodiversity group	Low biodiversity group	SEM[3]	Significance[4]
C16:0	Dairy	Cattle	16	25.21	25.04	1.547	ns
		Sheep	8	20.94	21.62	0.669	ns
	Meat	Sheep	14	21.63	24.27	1.083	*
C18:1trans11	Dairy	Cattle	12	3.37	3.07	0.190	**
		Sheep	9	5.18	4.49	0.487	ns
	Meat	Sheep	6	3.14	3.15	0.794	ns
C18:1cis9	Dairy	Cattle	19	22.63	21.78	1.347	ns
		Sheep	8	19.02	19.17	0.536	ns
	Meat	Sheep	14	31.12	30.97	1.540	ns
C18:2n-6	Dairy	Cattle	19	1.80	1.64	0.083	*
		Sheep	9	2.46	2.23	0.142	*
	Meat	Sheep	14	5.27	5.34	0.764	ns
C18:3n-3	Dairy	Cattle	16	0.93	0.82	0.051	*
		Sheep	9	1.61	1.35	0.080	*
	Meat	Sheep	14	2.14	2.28	0.225	ns
CLAcis9trans11	Dairy	Cattle	19	1.40	1.22	0.092	*
		Sheep	9	2.48	2.15	0.219	†
	Meat	Sheep	10	0.92	0.86	0.090	ns
SFA	Dairy	Cattle	18	60.51	62.63	1.164	**
		Sheep	8	65.70	65.94	2.714	ns
	Meat	Sheep	15	46.78	47.36	1.606	ns
MUFA	Dairy	Cattle	16	31.81	29.86	0.904	**
		Sheep	8	24.68	24.03	0.558	*
	Meat	Sheep	14	37.43	37.44	1.150	ns
PUFA	Dairy	Cattle	18	5.43	4.82	0.267	**
		Sheep	8	6.71	5.82	0.417	*
	Meat	Sheep	15	11.91	11.61	1.591	ns
BCFA	Dairy	Cattle	13	2.19	2.11	0.170	ns
	Meat	Sheep	5	5.74	5.48	0.585	ns
C18:1cis9/C16:0	Dairy	Cattle	16	0.90	0.79	0.036	**
		Sheep	8	1.28	1.30	0.179	ns
	Meat	Sheep	8	0.19	1.17	0.125	ns
C18:3n-3/C18:2n-6	Dairy	Cattle	16	0.56	0.53	0.027	*
		Sheep	8	0.67	0.62	0.056	ns
	Meat	Sheep	14	0.57	0.61	0.141	ns

[1] SFA, sum of straight-chain FA from C4:0 to C24:0; MUFA, sum of monounsaturated FA from C10:1 to C24:1; PUFA, sum of polyunsaturated FA from C18:2 to C22:6, BCFA, sum of branched chain FA from C13:0-iso to C18:0-iso.

[2] *n*, number of studies.

[3] SEM, standard error of the mean.

[4] ***, $P < 0.001$; **, $P < 0.01$; *, $P < 0.05$; †, $P < 0.1$; ns, not significant.

tocopherol content but a higher β-carotene content than grasses (Nozière et al., 2006). Herbage terpene content is also highly variable between plant species (Mariaca et al., 1997; Cabiddu et al., 2019), conferring specific terpene fingerprints to dairy products (Bovolenta et al., 2014; Aprea et al., 2016). Accordingly, single terpenoids may allow for a more robust discrimination than total terpenes between animal products from grasslands with different biodiversity levels (Moran et al., 2019). However, for the same botanical intraspecific variability, this result of terpene profile is valuable only under controlled experimental conditions and cannot be generalised to on-farm conditions. Recently, Renna et al. (2020) reported an important scientific upgrade on the effect of pasture characteristics on DC. The authors studied the hierarchy of herbage-related factors affecting milk FA composition. However, there is no such study for other quality traits and animal PCs.

Finally, another important confounding factor may be the animal characteristics. Even if animal-related factors (e.g. lactation stage, breed, and parity) only marginally affect the quality traits of dairy products, this is not the case for meat (Prache et al., 2020). Animal breed, age, sex, and duration and type of the finishing period affect meat quality. In particular, fattening period duration and initial weight at the beginning of this period affect meat composition and sensory traits in small and large ruminants depending on the animal category (Soulat et al., 2016; De Brito et al., 2017). Regarding MS, studies conducted in different regions (both under controlled or on-farm conditions) have drawn different conclusions, and their results should be generalised with caution. For instance, young male lambs are almost exclusively destined for a short fattening period in the Mediterranean regions, whereas older sheep of both sexes are slaughtered in Australia. Moreover, different levels of intramuscular fat affect the meat FA profile. In several studies aimed at comparing the effects of different feeding systems on meat FAs, the diets offered to the animals were periodically adjusted to achieve comparable growth rates (Luciano et al., 2009; Scerra et al., 2011).

Conclusions

To the best of our knowledge, this is the first quantitative review to investigate the effects of farming practices on a wide array of quality traits (carotenoids, fat-soluble vitamins, colour, FA, terpenes, and sensory properties) of dairy and meat products in cattle and small ruminants. The effects under controlled trials reported in the literature were corroborated on farms only for a part of the addressed quality traits, and when these differences were significant, the extent of effect under on-farm conditions was lower than under controlled conditions. Several confounding factors, for which there is no experimental control when operating on farm, may be the reason for these differences (i.e. mixed diets, phenological stage, and botanical composition of herbage, and animal-related factors). However, differences in several quality traits according to farming practices were confirmed. Specifically, feeding fresh herbage instead of conserved forage to animals affected the quality traits common to several PCs, particularly FA composition, probably because of the higher number of studies conducted on farms on these quality traits. It is not surprising that differences between farming practices emerged more frequently for parameters with a higher number of available studies within a PC. However, the high variability in the reference dataset resulting from the pooling of data obtained under heterogeneous conditions on farms could only be partially compensated by the high number of studies included in the statistical analysis. Further studies are required to reinforce the available knowledge on the effect of the studied farming practices: this is the case for meat products (MC in particular) and for all goat products.

Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.animal.2021.100375.

Ethics approval

Not applicable.

Data and model availability statement

Neither the data nor the model were deposited in an official repository.

Author ORCIDs

Cabiddu Andrea: https://orcid.org/0000-0002-2077-4201
Peratoner Giovanni: https://orcid.org/0000-0001-5021-2990
Valenti Bernardo: https://orcid.org/0000-0002-5737-9862
Monteils Valérie: https://orcid.org/0000-0002-9234-3451
Martin Bruno: https://orcid.org/0000-0003-2501-8306
Coppa Mauro: https://orcid.org/0000-0003-2073-0599

Author contribution

A. Cabiddu: validation, data curation, writing - original draft.

G. Peratoner: conceptualization, validation, writing - review & editing, supervision.

B. Valenti: data curation, writing - original draft.

V. Monteils: data curation, writing - original draft.

B. Martin: data curation, validation, writing - original draft.

M. Coppa: conceptualization, methodology, formal analysis, writing - original draft, writing - review & editing, supervision.

Declaration of interest

None.

Acknowledgments

This review was inspired by the work of the EIP-AGRI focus group 'Profitability of permanent grassland' (2014–2015), and particularly by the minipaper 'Differentiation of grass based products for higher market value: linking quality traits and management practices related to the ecosystem services', from which the definition of the feeding management strategies were adopted. The authors also thank Lisa Della Rosa for her support in assembling the list of references.

Financial support statement

This work is part of the collective scientific expertise (ESCo) on the "Quality of animal-derived foods according to animal production and processing conditions" that was carried out by INRAE at the request of the French ministry responsible for Agriculture and Food, in cooperation with the agency FranceAgriMer. The authors are grateful to the other experts from ESCo panel for their fruitful discussions.

This work was carried out with funds from the French Ministry of Agriculture and Food (agreement No 2017-424-2102316438) and the FranceAgriMer agency (agreement No 181911).

Transparency Declaration

This article is part of a supplement entitled '*Quality of animal-source foods*' supported by the French National Research Institute for Agriculture, Food, and Environment – INRAE.

References

Abilleira, E.M., de Renobales, A.I., Najera, M., Virto, J.C., Ruiz de Gordoa, F.J., Perez-Elortondo, M.A., Barron, L.J.R., 2010. An accurate quantitative method for the analysis of terpenes in milk fat by headspace solid-phase microextraction coupled to gas chromatography-mass spectrometry. Food Chemistry 120, 1162–1169. https://doi.org/10.1016/j.foodchem.2009.11.050.

Agabriel, C., Martin, B., Sibra, C., Bonnefoy, J.C., Montel, M.C., Didienne, R., Hulin, S., 2004. Effect of dairy production system on the sensory characteristics of Cantal cheeses, a plant-scale study. Animal Research 53, 221–234. https://doi.org/10.1051/animres:2004013.

Aprea, E., Romanzin, A., Corazzin, M., Favotto, S., Betta, E., Gasperi, F., Bovolenta, S., 2016. Effects of grazing cow diet on volatile compounds as well as physicochemical and sensory characteristics of 12-month-ripened Montasio cheese. Journal of Dairy Science 99, 6180–6190. https://doi.org/10.3168/jds.2016-10929.

Astrup, A., Magkos, F., Bier, D.M., Brenna, J.T., de Oliveira, O.M.C., Hill, J.O., King, J.C., Mente, A., Ordovas, J.M., Volek, J.S., Yusuf, S., Krauss, R.M., 2020. Saturated Fats and Health: A reassessment and proposal for food-based recommendations: JACC state-of-the-art review. Journals of the American College of Cardiology 76, 844–857. https://doi.org/10.1016/j.jacc.2020.05.077.

Biondi, L., Valvo, M.A., Di Gloria, M., Scinardo Tenghi, E., Galofaro, V., Priolo, A., 2008. Changes in ewe milk fatty acids following turning out to pasture. Small Ruminant Research 75, 17–23. https://doi.org/10.1016/j.smallrumres.2007.07.004.

Botana, A., Resch-Zafra, C., Pereira-Crespo, S., Veiga, M., González, L., Dagnac, T., Lorenzana, R., Fernández-Lorenzo, B., Flores-Calvete, G., 2018. Contrasting diets and milk composition on galician dairy farms. Grassland Science in Europe 23, 697–709.

Bovolenta, S., Romanzin, A., Corazzin, M., Spanghero, M., Aprea, E., Gasperi, F., Piasentier, E., 2014. Volatile compounds and sensory properties of Montasio cheese made from the milk of Simmental cows grazing on alpine pastures. Journal of Dairy Science 97, 7373–7385. https://doi.org/10.3168/jds.2014-8396.

Bronkema, S.M., Rowntree, J.E., Jain, R., Schweihofer, J.P., Bitler, C.A., Fenton, J.I., 2019. A nutritional survey of commercially available grass-finished beef. Meat and Muscle Biology 3 (1). https://doi.org/10.22175/mmb2018.10.0034.

Buccioni, A., Decandia, M., Minieri, S., Molle, G., Cabiddu, A., 2012. Lipid metabolism in the rumen: new insights on lipolysis and biohydrogenation with an emphasis on the role of endogenous plant factors. Animal Feed Science and Technology 174, 1–25. https://doi.org/10.1016/j.anifeedsci.2012.02.009.

Cabiddu, A., Wencelová, M., Bomboi, G., Decandia, M., Molle, G., Salis, L., 2017. Fatty acid profile in two berseem clover (Trifolium alexandrinum L.) cultivars: Preliminary study of the effect of part of plant and phenological stage. Grassland Science 63, 101–110. https://doi.org/10.1111/grs.12159.

Cabiddu, A., Delgadillo-Puga, C., Decandia, M., Molle, G., 2019. Extensive ruminant production systems and milk quality with emphasis on unsaturated fatty acids, volatile compounds, antioxidant protection degree and phenol content. Animals 9, 771. https://doi.org/10.3390/ani9100771.

Chassaing, C., Sibra, C., Verbič, J., Harstad, O.M., Golecký, J., Martin, B., Ferlay, A., Constant, I., Delavaud, C., Hurtaud, C., Pongrac, V.Ž., Agabriel, C., 2016. Mineral, vitamin A and fat composition of bulk milk related to European production conditions throughout the year. Dairy Science and Technology 96, 715–733. https://doi.org/10.1007/s13594-016-0300-7.

Chilliard, Y., Glasser, F., Ferlay, A., Bernard, L., Rouel, J., Doreau, M., 2007. Diet, rumen biohydrogenation and nutritional quality of cow and goat milk fat. European Journal of Lipid Science and Technology 109, 828–855. https://doi.org/10.1002/ejlt.200700080.

Coppa, M., Farruggia, A., Pradel, P., Lombardi, G., Martin, B., 2011. An improved grazed class method to estimate species selection and dry matter intake by cows at pasture. Italian Journal of Animal Science 10, 58–65. https://doi.org/10.4081/ijas.2011.e13.

Coppa, M., Farruggia, A., Ravaglia, P., Pomiés, D., Borreani, G., Le Morvan, A., Ferlay, A., 2015. Frequent moving of grazing dairy cows to new paddocks increases the variability of milk fatty acid composition. Animal 9, 604–613. https://doi.org/10.1017/S1751731114003000.

Coppa, M., Chassaing, C., Sibra, C., Cornu, A., Verbič, J., Golecký, J., Engel, E., Ratel, J., Boudon, A., Ferlay, A., Martin, B., 2019. Forage system is the key driver of mountain milk specificity. Journal of Dairy Science 102, 10483–10499. https://doi.org/10.3168/jds.2019-16726.

Couvreur, S., Hurtaud, C., Lopez, C., Delaby, L., Peyraud, J.L., 2006. The linear relationship between the proportion of fresh grass in the cow diet, milk fatty acid composition, and butter properties. Journal of Dairy Science 89, 1956–1969. https://doi.org/10.3168/jds.S0022-0302(06)72263-9.

Croissant, E.A., Washburn, S.P., Dean, L.L., Drake, D.A., 2007. Chemical properties and consumer perception of fluid milk from conventional and pasture-based production systems. Journal of Dairy Science 90, 4924–4953. https://doi.org/10.3168/jds.2007-0456.

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. Nutrition Journal 9, 10. https://doi.org/10.1186/1475-2891-9-10.

De Brito, G.F., Ponnampalam, E.N., Hopkins, D.L., 2017. The effect of extensive feeding systems on growth rate, carcass traits, and meat quality of finishing lambs. Comprehensive Reviews in Food Science and Food Safety 16, 23–38. https://doi.org/10.1111/1541-4337.12230.

De La Torre, A., Gruffat, D., Durand, D., Micol, D., Peyron, A., Scislowski, V., Bauchart, D., 2005. Factors influencing proportion and composition of CLA in beef. Meat Science 73, 258–268. https://doi.org/10.1016/j.meatsci.2005.11.025.

Elgersma, A., 2015. Grazing increases the unsaturated fatty acid concentration of milk from grass-fed cows: A review of the contributing factors, challenges and future perspectives. European Journal of Lipid Science and Technology 117, 1345–1369. https://doi.org/10.1002/ejlt.201400469.

Farruggia, A., Pomiès, D., Coppa, M., Ferlay, A., Verdier-Metz, I., Le Morvan, A., Bethier, A., Pompanon, F., Troquier, O., Martin, B., 2014. Animal performances, pasture biodiversity and dairy product quality: how it works in contrasted mountain grazing systems. Agriculture Ecosystems and Environment 185, 231–244. https://doi.org/10.1016/j.agee.2014.01.001.

Ferlay, A., Martin, B., Pradel, P., Coulon, J.B., Chilliard, Y., 2006. Influence of grass-based diets on milk fatty acid composition and milk lipolytic system in Tarentaise and Montbeliarde cow breeds. Journal of Dairy Science 89, 4026–4041. https://doi.org/10.3168/jds.S0022-0302(06)72446-8.

Fraser, M.D., Davies, D.A., Vale, J.E., Nute, G.R., Hallett, K.G., Richardson, R.I., Wright, I.A., 2009. Performance and meat quality of native and continental cross steers grazing improved upland pasture or semi-natural rough grazing. Livestock Science 123, 70–82. https://doi.org/10.1016/j.livsci.2008.10.008.

Frétin, M., Martin, B., Buchin, S., Deserre, B., Lavigne, R., Tixier, E., Cirié, C., Bord, C., Montel, M.C., Delbes, C., Ferlay, A., 2019. Milk fat composition modifies the texture and appearance of Cantal-type cheeses but not their flavor. Journal of Dairy Science 102, 1131–1143. https://doi.org/10.3168/jds.2018-15534.

Gallo, S.B., Arrigoni, M.B., Lemos, A.L.D.C., Haguiwara, M.M.H., Bezerra, H.V.A., 2019. Influence of lamb finishing system on animal performance and meat quality. Acta Scientiarum Animal Sciences 41, e44742. https://doi.org/10.4025/actascianimsci.v41i1.44742.

Giaccone, D., Revello-Chion, A., Galassi, L., Bianchi, P., Battelli, G., Coppa, M., Tabacco, E., Borreani, G., 2016. Effect of milk thermisation and farming system on cheese sensory profile and fatty acid composition. International Dairy Journal 59, 10–19. https://doi.org/10.1016/j.idairyj.2016.02.047.

Givens, D.I., 2010. Milk and meat in our diet: Good or bad for health? Animal 4, 1941–1952. https://doi.org/10.1017/S1751731110001503.

Gratani, L., Varone, L., 2004. Leaf key traits of Erica arborea L., Erica multiflora L. and Rosmarinus officinalis L. co-occurring in the Mediterranean maquis. Flora 199, 58–69. https://doi.org/10.1078/0367-2530-00130.

Gwin, L., 2009. Scaling-up sustainable livestock production: Innovation and challenges for grass-fed beef in the US. Journal of Sustainable Agriculture 33, 189–209. https://doi.org/10.1080/10440040802660095.

Hooper, L., Martin, N., Jimoh, O.F., Kirk, C., Foster, E., Abdelhamid, A.S., 2020. Reduction in saturated fat intake for cardiovascular disease. Cochrane Database System Review 5, CD011737. https://doi.org/10.1002/14651858.CD011737.pub2.

Hurtaud, C., Peyraud, J.L., Michel, G., Berthelod, D., Delaby, L., 2009. Winter feeding systems and dairy cow breed have an impact on milk composition and flavour of two Protected Designation of Origin French cheeses. Animal 3, 1327–1338. https://doi.org/10.1017/S1751731109004716.

Khanal, R.C., Dhiman, T.R., Boman, R.L., 2008. Changes in fatty acid composition of milk from lactating dairy cows during transition to and from pasture. Livestock Science 114, 164–175. https://doi.org/10.1016/j.livsci.2007.04.020.

Luciano, G., Biondi, L., Pagano, R.I., Scerra, M., Vasta, V., López-Andrés, P., Valenti, B., Lanza, M., Priolo, A., Avondo, M., 2009. The restriction of grazing duration does not compromise lamb meat colour and oxidative stability. Meat Science 92, 30–35. https://doi.org/10.1016/j.meatsci.2012.03.017.

Mancilla-Leytón, J.M., Vicente, A.M., Delgado-Pertíñez, M., 2013. Summer diet selection of dairy goats grazing in a Mediterranean shrubland and the quality of secreted fat. Small Ruminant Research 113, 437–445. https://doi.org/10.1016/j.smallrumres.2013.04.010.

Mariaca, R.G., Berger, T.F.H., Gauch, R., Imhof, M.I., Jeangros, B., Bosset, J.O., 1997. Occurrence of volatile mono- and sesquiterpenoids in highland and lowland plant species as possible precursors for flavor compounds in milk and dairy products. Journal of Agricultural Food Chemistry 45, 4423–4434. https://doi.org/10.1021/jf970216t.

Martin, B., Verdier-Metz, I., Buchin, S., Hurtaud, C., Coulon, J.B., 2005. How does the nature of forages and pastures diversity influence the sensory quality of dairy livestock products? Animal Science 81, 205–212. https://doi.org/10.1079/ASC50800205.

Minchin, W., Buckley, F., Kenny, D.A., Monahan, F.J., Shalloo, L., O'Donovan, M., 2010. An evaluation of over-wintering feeding strategies prior to finishing at pasture for cull dairy cows on live animal performance, carcass and meat quality characteristics. Meat Science 85, 385–393. https://doi.org/10.1016/j.meatsci.2008.07.001.

Molle, G., Decandia, M., Giovanetti, V., Manca, C., Acciaro, M., Epifani, G., Salis, L., Cabiddu, A., Sitzia, M., Cannas, A., 2017. Grazing behaviour, intake and performance of dairy ewes with restricted access time to berseem clover (Trifolium alexandrinum L.) pasture. Grass and Forage Science 72, 194–210. https://doi.org/10.1111/gfs.12228.

Monteils, V., Sibra, C., 2019. Rearing practices in each life period of beef heifers can be used to influence the carcass characteristics. Italian Journal of Animal Science 18, 734–745. https://doi.org/10.1080/1828051X.2019.1569486.

Moran, L., Aldezabal, A., Aldai, N., Barrona, L.J.R., 2019. Terpenoid traceability of commercial sheep cheeses produced in mountain and valley farms: from pasture to mature cheeses. Food Research International 126, 108669. https://doi.org/10.1016/j.foodres.2019.108669.

Nozière, P., Graulet, B., Lucas, A., Martin, B., Grolier, P., Doreau, M., 2006. Carotenoids for ruminants, from forages to dairy products. Animal Feed Science and Technology 131, 418–450. https://doi.org/10.1016/j.anifeedsci.2006.06.018.

Piccinali, P., 2012. Aroma wheel for hard and semi-hard cheese 2 pp. Agroscope, Bern https://www.agroscope.admin.ch/agroscope/en/home/topics/food/sensory-analysis/milchprodukte–kaese/aromarad-kaese-und-milchprodukte.html.

Prache, S., Martin, B., Coppa, M., 2020. Review: Authentication of grass-fed meat and dairy products from cattle and sheep. Animal 14, 854–863. https://doi.org/10.1017/S1751731119002568.

Renna, M., Ferlay, A., Lussiana, C., Bany, D., Graulet, B., Wyss, U., Enri, S.R., Battaglini, L.M., Coppa, M., 2020. Relative hierarchy of farming practices affecting the fatty acid composition of permanent grasslands and of the derived bulk milk. Animal Feed Science and Technology 267,. https://doi.org/10.1016/j.anifeedsci.2020.114561 114561.

Scerra, M., Luciano, G., Caparra, P., Foti, F., Cilione, C., Giorgi, A., Scerra, V., 2011. Influence of stall finishing duration of Italian Merino lambs raised on pasture on intramuscular fatty acid composition. Meat Science 89, 238–242. https://doi.org/10.1016/j.meatsci.2011.04.012.

Schreurs, N.M., McNabb, W.C., Tavendale, M.H., Lane, G.A., Barry, T.N., Cummings, T., Fraser, K., Lopez-Villalobos, N., Ramırez-Restrepo, C.A., 2007. Skatole and indole concentration and the odour of fat from lambs that had grazed perennial ryegrass/white clover pasture or Lotus corniculatus. Animal Feed Science and Technology 138, 254–271. https://doi.org/10.1016/j.anifeedsci.2006.11.020.

Sinclair, L.A., 2007. Nutritional manipulation of the fatty acid composition of sheep meat: a review. 2007. Journal of Agricultural Science 145, 419–434. https://doi.org/10.1017/S0021859607007186.

Serrano, E., Cornu, A., Kondjoyan, N., Agabriel, J., Micol, D., 2011. Traceability of grass feeding in beef: terpenes, 2,3-octanedione and skatole accumulation in adipose tissue of young bulls. Animal 5, 641–649. https://doi.org/10.1017/S1751731110002296.

Soulat, J., Picard, B., Leger, S., Monteils, V., 2016. Prediction of beef carcass and meat traits from rearing factors in young bulls and cull cows. Journal of Animal Science 94, 1712–1726. https://doi.org/10.2527/jas.2015-0164.

Stergiadis, S., Leifert, C., Seal, C.J., Eyre, M.D., Larsen, M.K., Slots, T., Nielsen, J.H., Butler, G., 2015. A 2-year study on milk quality from three pasture-based dairy systems of contrasting production intensities in Wales. Journal of Agricultural Science 153, 708–731. https://doi.org/10.1017/S0021859614000963.

Tornambé, G., Cornu, A., Pradel, P., Kondjoyan, N., Carnat, A.P., Petit, M., Martin, B., 2006. Changes in terpene content in milk from pasture-fed cows. Journal of Dairy Science 89, 2309–2319. https://doi.org/10.3168/jds.S0022-0302(06)72302-5.

Valdivielso, I., Bustamante, M.A., Aldezabal, A., Amores, G., Virto, M., Ruiz de Gordoa, J.C., de Renobales, M., Barron, L.J.R., 2016. Case study of a commercial sheep flock under extensive mountain grazing: Pasture derived lipid compounds in milk and cheese. Food Chemistry 197, 622–633. https://doi.org/10.1016/j.foodchem.2015.10.133.

Vasta, V., Priolo, A., 2006. Ruminant fat volatiles as affected by diet. A review. Meat Science 73, 218–228. https://doi.org/10.1016/j.meatsci.2005.11.017.

Villalba, J.J., Provenza, F.D., Clemensen, K.A., Larsen, R., Juhnke, J., 2011. Preference for diverse pastures by sheep in response to intraruminal administrations of tannins, saponins and alkaloids. Grass and Forage Science 66, 224–236. https://doi.org/10.1111/j.1365-2494.2010.00779.x.