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

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18

19 **ABSTRACT**

20 In the last decades, a large body of evidence has highlighted the major
21 role of feeding management practices in improving specific nutritional,
22 technological and sensory quality traits of ruminant products. However,
23 results have been mostly obtained under controlled conditions, and have
24 been rarely validated on-farm. Therefore, a quantitative review was
25 conducted to quantify the effects of on-farm feeding management
26 practices on carotenoids, fat-soluble vitamins, colour, fatty acids (FA),
27 terpenes and sensory properties in the main animal products categories
28 (PC): dairy products from cattle (DC), sheep (DS) and goat (DG), and
29 meat from cattle (MC) and sheep (MS). Four feeding scenarios were
30 selected according to the consistency of on-farm studies in the literature:
31 a) feeding “Fresh herbage” instead of conserved forages; b) ban any form
32 of silage (“Silage-free”) c) ban maize silage (“Maize silage-free”); d)
33 feeding forages from permanent grasslands rich in species or plant
34 secondary metabolites (PSM) (“PSM-rich permanent grassland”). Feeding
35 fresh herbage increased the concentration of carotenoids, fat-soluble
36 vitamin, n-3 FA, rumenic acid, and branched chain FA (BCFA), and
37 reduced the concentration of saturated FA, for all PC, with overall stronger
38 effect for dairy products than for meat. The texture of meat and dairy
39 products was marginally affected, whereas feeding fresh herbage
40 decreased lactic and increased vegetal notes in DC. The “Silage-free”
41 feeding scenario resulted in increased vaccenic acid, rumenic acid, BCFA,

42 and C18:3n-3 in DC. The “Maize silage-free” feeding scenario lowered n-6
43 FA whereas increased n-3, rumenic acid and BCFA concentrations in DC.
44 Feeding ruminants with forages from “PSM-rich permanent grasslands”,
45 increased monounsaturated FA, n-3 FA and rumenic acid and decreased
46 n-6 FA in dairy products, and only marginally affected meat FA
47 composition. The DC from “PSM-rich permanent grasslands” showed
48 higher intense, spicy and animal notes. Overall, the differences between
49 feeding management practices observed on farm were smaller than those
50 observed under controlled trials. Several confounding factors, not
51 controlled when operating under on-farm conditions, could be at the origin
52 of these divergences (i.e. mixed diets, forage characteristics, animal-
53 related factors). This review confirmed that farming practices may
54 differently affect several quality traits of ruminant products. It also
55 highlighted the uneven knowledge on the effect of feeding management
56 depending on the PC: larger for milk than for meat and decreasing when
57 moving from cattle to sheep and from sheep to goat.

58 **Keywords:** fatty acids, carotenoids, colour, terpenoids, sensory
59 properties.

60

61 **Implications**

62 Feeding management practices are the most impacting factors to improve
63 nutritional, technological and sensory quality of ruminant products in
64 controlled experiments. However, most studies were conducted under

65 controlled conditions. This review aims at quantifying these effects of
66 feeding management on farm. We identified common feeding
67 management practices able to enhance the quality of cattle and small
68 ruminants meat and dairy products. Factors weakening the expected
69 effects on quality traits on farm were highlighted. This review provides
70 sound information to the stakeholders of ruminant production chains for
71 implementing effective feeding management practices to achieve the
72 targeted quality of ruminant products.

73

74 **Introduction**

75 Globally, consumers are increasingly demanding for animal products with
76 a high safety standard, nutritional value, and sensory quality, which are, at
77 the same time, obtained through environment- and animal-friendly
78 practices. To achieve these goals, feeding management is one of the most
79 effective strategies (Prache *et al.*, 2020; Cabiddu *et al.* 2019; Minchin *et*
80 *al.*, 2010). By feeding herbage to ruminants (particularly when grazed),
81 dairy and meat products with specific traits are produced. They are rich in
82 carotenoids, vitamins A and E (Nozière *et al.*, 2006; Prache *et al.*, 2020),
83 volatile organic compounds (VOCs), and fatty acids (FA) favourable for
84 human nutrition [e.g. monounsaturated FA (MUFA), polyunsaturated FA
85 (PUFA), and n-3 FA] (Coppa *et al.*, 2019; Cabiddu *et al.*, 2019; Scerra *et*
86 *al.*, 2011), and have specific sensory characteristics, preferred by
87 consumers (Martin *et al.*, 2005). For some products, however, the

88 opposite is true. For instance, certain maize silage and concentrate-based
89 dairy products, such as butter, have been historically preferred for their
90 firmness because the high melting point of fats therein [due to the richness
91 in saturated FA (SFA)], as this make them easy to be transported and
92 commercialised even far from the production area (Prache *et al.*, 2020).
93 Similarly, the U.S. population prefers the sensory characteristics of grain-
94 finished animals (Gwin, 2009).

95 Most feeding strategies that improve the quality of animal products have
96 been tested under controlled conditions (Ferlay *et al.*, 2006; Hurtaud *et al.*,
97 2009 for dairy products from cattle; Cabiddu *et al.* 2019 for dairy products
98 from small ruminant; Fraser *et al.*, 2009; and Luciano *et al.*, 2009 for
99 meat). However, under on-farm conditions, other uncontrolled and
100 unstandardised factors (e.g. forage characteristics, animal status, feeding
101 behaviour, and farm management, among others) may interact and thus
102 amplify, confound, or overrule the effects of the employed practices,
103 ultimately affecting the product quality in controlled trials.

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

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

121 **Materials and methods**

122 ***Data collection and selection of quality traits***

123 Scientific publications were identified through an initial search of literature
124 in the Web of Knowledge and Scopus databases using several search
125 keywords related to the effect of farm management practices on different
126 quality traits of animal products (i.e. pasture*, fresh herbage*, silage*,
127 maize*, hay*, and biodiversity*). Animal species, animal product type, and
128 each quality trait were used as the keywords. Experiments performed
129 under controlled conditions or on experimental farms were excluded, but
130 those reporting data from commercial farms were selected. The data on
131 animal product quality traits and farming practices were collected from
132 peer-reviewed papers and conference proceedings that were published
133 between 1996 and 2019, included proper statistical analyses, and reported

134 probability values for the investigated factors. Only studies that provided
135 detailed information on the proportion of feedstuff on a DM basis and in
136 which at least two farming practices were compared were included. A
137 complete list of the included studies is provided in the supplementary
138 material. A total of 98 studies were included, 70 of which were on dairy
139 products and 28 on meat products; 45 studies dealt with cattle, 12 with
140 goat, and 41 with sheep. There was no study on goat meat. Five product
141 categories (PC) were defined by combining the animal product type and
142 species: dairy cattle (DC), dairy goats (DG), dairy sheep (DS), meat cattle
143 (MC), and meat sheep (MS). Quality traits having an interest for human
144 nutrition and health or with an effect on the sensory profile of animal
145 products were evaluated, as well as the sensory profile itself. In particular,
146 fat-soluble vitamins and carotenoids were considered due to the
147 antioxidant potential for humans and their influence on dairy products
148 colour (Nozière *et al.*, 2006). The MUFA, PUFA, C18:1cis9, C18:3n-3 (the
149 main n-3 FA in animal products) and its ratio to C18:2n-6 (the main n-6 FA
150 in animal products), branched chain FA (BCFA), rumenic acid
151 (CLAcis9trans11) and its precursor C18:1trans11 were included because
152 of their potential positive effect on human health (potential contribution to
153 the prevention against cardiovascular diseases, cancer, obesity, etc.)
154 (Givens, 2010). The effect positive or negative effect of SFA and C18:2n-
155 6 on human health is still in debate: i.e. Hooper *et al.*, (2020) showed that
156 a reduction in SFA intake could help to prevent cardiovascular diseases,

157 but Astrup *et al.*, (2020) highlighted that the intake of SFA from whole fat
158 dairy and unprocessed meat is not associated with increased risk of
159 cardiovascular diseases. Some FA (SFA, MUFA, PUFA, C18:1cis9/C16:0)
160 affect the fat melting point with consequences on the texture of animal
161 products. Moreover, PUFA can contribute to develop odour active
162 compounds through oxidation (Martin *et al.*, 2005). Mono-, sesqui-, and
163 total terpenes can potentially play a role on sensory profile as odour active
164 compounds (Martin *et al.*, 2005). Both instrumentally measured sensory
165 traits, such as colour and texture, pH at 24 h (only for meat), and those
166 evaluated by panel tests (colour, appearance, texture, odour, flavour, and
167 taste) were considered. Only quality traits for which data from at least
168 three publications in a feeding scenario were available were included in
169 the statistical analysis. Several other quality traits were also found in the
170 literature (i.e. other FA, single terpenes, total antioxidant capacity, muscle
171 water holding capacity and microstructure, and cheese granular texture),
172 but the available data were limited to yield reliable statistics; thus, such
173 traits were not considered in the present review. As sensory attributes are
174 often specific to a product (particularly dairy products), they were grouped
175 under sensory families, as described by Piccinali (2012), based on odour,
176 flavour, and taste: intensity, spicy, lactic (acid, milk, yoghurt, cream,
177 fermented cream, and butter), fruity (hazelnut), vegetal (grassy, boiled
178 vegetables, garlic, and onion), brown (caramel, smoked, sweet, and
179 vanilla), animal (animal, stable, barn, and manure), and others (salty,

180 bitter, silage, mould, mothball, and cheese mite). Data on floral and spicy
181 sensory families were limited. Furthermore, texture properties (firm and
182 elastic), including meat tenderness, fattiness, juiciness, and visually
183 estimated intramuscular fat, were considered.

184 When quality traits were expressed using different units of measurement
185 in different studies, the data were converted to a common unit [$\text{mg}\cdot\text{kg}^{-1}$
186 DM to $\text{mg}\cdot\text{kg}^{-1}$ fat for fat-soluble vitamins, $\text{g}\cdot 100\text{ g}^{-1}$ milk or $\text{g}\cdot 100\text{ g}^{-1}$ DM to
187 $\text{g}\cdot 100\text{ g}^{-1}$ FA for FA, 10^6 arbitrary area unit (AAU) to \ln (natural logarithm)
188 of AAU for terpenes, and 0-n to a 0–10 scale for sensory descriptors].

189 ***Selection of management practices***

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

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

- 195 1. Inclusion of fresh herbage in the diet instead of feeding conserved
196 forage and/or concentrates (*fresh herbage*)
- 197 2. Renunciation to feed any form of silages in conserved forage- or
198 pasture-based systems during the winter period (but approval to feed
199 hay) (*silage-free*)
- 200 3. Renunciation to feed maize silage, including the winter periods in
201 pasture-based systems, but approval to feed grass silage (*maize silage-*
202 *free*)

203 4. Use of forages from permanent grasslands rich in species or plant
204 secondary metabolites (PSM) instead of temporary grasslands
205 dominated by grasses or poor in PSM (*PSM-rich permanent*
206 *grasslands*).

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

212 ***Statistical analysis***

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

$$222 \quad \Delta\% = \frac{X1 - X0}{X0} \times 100$$

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

225 Then, general linear model (GLM) analysis was performed, considering
226 the respective DM $\Delta\%$ of fresh herbage in the diet as a covariate. PC and
227 their interactions with the covariate were included as the fixed effects to
228 estimate the differences among PC and detecting various responses to
229 the corresponding feeding practice. Considering the great variability of
230 experimental conditions in different studies included, eight or more cases
231 was considered the minimum number for each PC to be included in the
232 GLM analysis. Bonferroni post hoc test was performed to analyse
233 differences in PC and their interactions with the covariate (respective DM
234 $\Delta\%$ of fresh herbage in the diet). For other main feeding scenarios,
235 sufficient data were not available to perform the same analysis. All the
236 statistical analyses were performed using Minitab v. 14.1 (Minitab Inc.,
237 State College, PA, USA).

238 **Results and discussion**

239 ***Structure of the dataset***

240 Among all farming practices considered in this review, the effect of fresh
241 herbage inclusion in animal diets was the most studied under on-farm
242 conditions, but the number of available data varied according to the PCs
243 and quality traits considered. Overall, DC was the most studied category
244 (40 studies), followed by MS and DS (22 and 18 studies, respectively).
245 However, there were a few studies on DG (12 studies) and very few on
246 MC (5 studies); there was no study on goat meat. Furthermore, the studies
247 assessed the effects of feeding hay instead of silage or grass silage

248 instead of maize silage under on-farm conditions on DC alone, and studies
249 on other PCs were lacking. Moreover, the studies assessed the effects of
250 pasture plant diversity under on-farm conditions on DC, DS, and MS
251 alone. Furthermore, among the various quality traits, major FA
252 composition of dairy and meat products was the most widely studied for all
253 farming management practices analysed (61 studies), followed by colour
254 and carotenoids (18 studies), sensory characteristics (11 studies), and
255 total terpene content (7 studies).

256 The fresh herbage proportion (%DM) of animal diet in the dataset used to
257 investigate the 'fresh herbage' feeding scenario showed marked
258 differences between the "fresh herbage" and the "conserved forages"
259 groups (Table 1); its average proportion in the fresh herbage group ranged
260 between 61 and 100% within a PC, with a mean paired-sample difference
261 of 54-94%. The fresh herbage proportion of animal diet in the dataset used
262 to test the 'PSM-rich permanent grasslands' feeding scenario was
263 comparable between the high- and low-biodiversity groups, regardless of
264 the PC (85-100%, with a mean paired-sample difference of 1-2%; Table
265 1). Regarding the 'silage-free' feeding scenario, the proportion (%DM) of
266 hay in dairy cattle diet was $61 \pm 21.3\%$ (average \pm standard deviation;
267 range: 41-100%) and $8 \pm 8.1\%$ (range: 0-28%) in the hay and silage
268 groups, respectively, with a paired-sample difference of $53 \pm 24.0\%$
269 (range: 25-100%). In the 'maize silage-free' feeding scenario, the grass
270 silage proportion (%DM) of dairy cattle diet was $48 \pm 12.4\%$ (range 31-

271 61%) and $6 \pm 7.3\%$ (range: 0-18%) in the grass silage and maize silage
272 groups, respectively, with a paired-sample difference of $46 \pm 12.4\%$ (range
273 31-91%). Conversely, the maize silage proportion (%DM) was $1 \pm 1.9\%$
274 (range 0-4%) and $49 \pm 12.7\%$ (range 39-60%) in the grass silage and
275 maize silage groups, respectively, with a paired-sample difference of $49 \pm$
276 14.8% (range 39-59%).

277 ***Fresh herbage vs. conserved forage and concentrates***

278 *Carotenoids and colour*

279 A fresh herbage-containing diet increased the content of all carotenoids in
280 dairy and meat products (except retinol content in DC) compared with the
281 conserved forage (Table 2). This may be because carotenoids in herbage
282 are photodegraded during forage harvesting and drying (Nozière *et al.*,
283 2006). For DC, $\Delta\%$ was +30% for α -tocopherol, +41% for β -carotene,
284 +45% for zeaxanthin, and +63% for lutein. The α -tocopherol and β -
285 carotene content increased by respectively 0.9% and 1.8% per unit
286 increase in the fresh herbage proportion of animal diet ($R^2 = 0.67$ and
287 0.82 , respectively; Table 3). The extent of these differences is consistent
288 with the findings of controlled trials (Nozière *et al.*, 2006; Prache *et al.*,
289 2020). For DG, a similar increase was noted for retinol content and a
290 much larger increase for α -tocopherol content (approximately +480%).
291 This may be because only four data sources were available for DG, mostly
292 from studies conducted in Mediterranean shrubby areas, where shrub
293 leaves contain high amounts of α -tocopherol precursors to prevent

294 photooxidative damage in arid environments (Gratani and Varone, 2014).
295 Fresh herbage inclusion in animal diet also increased α -tocopherol content
296 (by 73%) in MS. The lack of difference in retinol content in DC contradicts
297 the increase in its content with fresh herbage inclusion in the diet found in
298 controlled trials (Nozière *et al.*, 2006). However, Chassaing *et al.* (2016)
299 highlighted the variability in the retinol content of milk in cattle receiving
300 conserved forage on commercial farms. Indeed, grass silage contains
301 more retinol than hay (Nozière *et al.*, 2006).

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

316 on dry matter contents could have contributed to weaken colour
317 differences.

318 *Terpenoids*

319 A fresh herbage-containing diet increased monoterpene (+10%) and total
320 terpene (+5%) content in DS compared with conserved forage. A similar
321 tendency ($P < 0.1$) was also observed for monoterpenes in DC (+9%).
322 Terpenes are PSM that are particularly abundant in dicots (Mariaca *et al.*,
323 1997) and can be transferred directly from herbage to milk and then to
324 cheese (Tornambé *et al.*, 2006). Being volatile, some of these compounds
325 are lost during forage harvesting and conservation, resulting in a lower
326 terpene content in dairy products derived from animals fed conserved
327 forage in controlled trials (Croissant *et al.*, 2007; Cabiddu *et al.*, 2019).
328 Thus, it was quite unexpected that neither monoterpenes nor total
329 terpenes in DC and sesquiterpenes in DS were affected by the presence
330 of fresh herbage in the animal diet. This lack of differences, contrary to
331 that observed in controlled trials, could be attributed to several
332 confounding factors, such as forage characteristics (discussed later) and
333 the terpene analytical methods used, which makes it difficult to generalise
334 the differences found in single studies (Abilleira *et al.*, 2010).

335 *Fatty acids*

336 Not all FA showed significant differences in all PCs (Table 4). Feeding
337 fresh herbage similarly affected the content of several FA in both dairy and
338 meat products. Specifically, it reduced the content of C16:0 (between -6%

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

353 The BCFA (content) of the products of DC increased when the animals
354 were fed fresh herbage rather than conserved forage (+11%; Table 4).
355 These FA are derived from ruminal cellulolytic bacteria (Buccioni *et al.*,
356 2012). In controlled trials (Couvreur *et al.*, 2006; Ferlay *et al.*, 2006), their
357 content in the milk of fresh herbage-fed cattle has been reported to be
358 higher because of the higher cellulose and hemicellulose content and fibre
359 digestibility of fresh herbage than of conserved forage (Couvreur *et al.*,
360 2006; Ferlay *et al.*, 2006).

361 Feeding fresh herbage instead of conserved forage increased the
362 C18:1cis9 and MUFA content in DC (+7% and +9%, respectively) and DS
363 (+13% and +17%, respectively), but did not affect the content of these FA
364 in meat, except for MUFA in MS (+6%) (Table 4). The C18:1cis9 content
365 of dairy products and that of MUFA in MS increased linearly by 0.2% with
366 per unit increase in the fresh herbage proportion of diet. A high C18:1cis9
367 content of animal products is related to fresh herbage intake (Elgersma *et*
368 *al.*, 2015). However, this FA is derived from multiple pathways. It can
369 originate from lipid mobilisation or mammary Δ^9 -desaturase action
370 (Chilliard *et al.*, 2007). The C18:1cis9/C16:0 ratio increased with the
371 increasing proportion of fresh herbage in DC (+17%) and DS (+22%); this
372 was expected because of the abovementioned results of single FA. Its
373 value increased by 0.3% with per unit increase in the fresh herbage
374 proportion of animal diet. This ratio, also called the spreadability index, is
375 related to the texture and sensory properties of dairy products (Hurtaud *et*
376 *al.*, 2009; Giaccone *et al.*, 2016; Chilliard *et al.*, 2007).

377 Furthermore, feeding fresh herbage strongly increased the content of
378 C18:3n-3, the major FA of fresh herbage (Elgersma *et al.*, 2015), in both
379 dairy and meat products of all species studied (+41% and +73%,
380 respectively) (Table 4). However, it decreased the C18:2n-6 content of
381 dairy (-14% in DC) and meat (between -15 and -18%). The C18:3n-3
382 content linearly increased by 1.1% with per unit increase in the fresh
383 herbage proportion of animal diet, regardless of the animal product ($R^2 =$

384 0.42; Table 3). Similar results were observed for C18:2n-6 (-0.2 % per unit
385 increase in the fresh herbage proportion of animal diet), although the
386 model fit was poor ($R^2 = 0.12$; Table 3). The C18:2n-6 is the second major
387 constituent of herbage lipids, but it is also abundant in maize silage and
388 cereal concentrates (Elgersma *et al.*, 2015). This implies that its content in
389 various products also depends on the type and proportion of conserved
390 forage and concentrate in the diet (Chilliard *et al.*, 2007; Daley *et al.*, 2010;
391 Sinclair, 2007). According to the differences observed for C18:3n-3 and
392 C18:2n-6, their ratio greatly increased (between 52 and 71% in dairy
393 products and between 77 and 124% in meat) when fresh herbage was
394 provided instead of conserved forages (Table 4). This ratio linearly
395 increased by 1.1% with per unit increase in the fresh herbage proportion of
396 animal diet, regardless of the animal products ($R^2 = 0.65$; Table 3). The
397 observed increase in the C18:3n-3 content by feeding fresh herbage-
398 based diets was greater (between 80 and 150%) in controlled trials
399 (Couvreur *et al.*, 2006; Biondi *et al.*, 2008; Daley *et al.*, 2010, Scerra *et al.*,
400 2011); however, the trend was similar, albeit sometimes not significant, for
401 C18:2n-6 (Couvreur *et al.* 2006; Khanal *et al.*, 2008), largely depending on
402 the type of conserved forage and concentrate. Compared to that in
403 conserved forage, C18:3n-3 in fresh herbage can be more efficiently
404 transferred to the animal products, as this FA is allocated to the
405 membrane lipids (Buccioni *et al.*, 2012).

406 The C18:1trans11 and CLAcis9trans11 content increased by respectively
407 72% and 94% in dairy products with the inclusion of fresh herbage in
408 animal diet (Table 4), consistent with the increase in C18:3n-3 and
409 C18:2n-6 content. In fact, C18:3n-3 and C18:2n-6 are partially
410 biohydrogenated to C18:1trans11 (Buccioni *et al.*, 2012), which is
411 desaturated in the mammary gland to CLAcis9trans11 (Chilliard *et al.*,
412 2007). Similarly, the C18:1trans11 content was significantly increased in
413 MS (+59%) and the CLAcis9trans11 content was increased in MC (+48%)
414 when the animals were fed fresh herbage. Such increases for both FA
415 have also been reported in controlled trials, albeit with a greater variability.
416 Ferlay *et al.* (2006) and Coppa *et al.* (2015) have reported consistent
417 increases under on-farm conditions, while other studies have reported
418 larger increases (between +150 and +478% for C18:1trans11 and
419 between +177 and +380%, with an extreme of +16% at the lower range,
420 for CLAcis9trans11) (Khanal *et al.*, 2008; Biondi *et al.*, 2008; Daley *et al.*,
421 2010). The C18:1trans11 content in all PCs linearly increased by 2.1%
422 with per unit increase in the fresh herbage proportion of animal diet ($R^2 =$
423 0.64; $P < 0.01$, Table 3). The CLAcis9trans11 content showed different
424 increasing trends between dairy and meat products; in the former, it
425 linearly increased by 0.7% and 0.6% with per unit increase in the fresh
426 herbage proportion of cattle and sheep diets, respectively, not differing
427 between dairy product category, but the slope coefficient of
428 CLAcis9trans11 in MC was not significant (Table 3). This difference in MC

429 could be due to the lower activity of Δ^9 -desaturase in the adipose tissue
430 than in the mammary gland (Chilliard *et al.* 2007) or partially due to the
431 heterogeneity of the dataset in terms of animal age and sex (De la Torre *et*
432 *al.*, 2006), coupled with a relatively low number (8) of available studies.

433 The PUFA content in dairy products increased between 17 and 23% with a
434 fresh herbage-based diet (Table 4), whereas no effect was observed for
435 meat. Its content in all dairy products increased by 0.6% with per unit
436 increase in the fresh herbage proportion of animal diet ($R^2 = 0.57$; $P <$
437 0.01) (Table 3). These results are consistent with those of controlled trials
438 on cattle (Chilliard *et al.* 2007) and goats (Mancilla-Leyton *et al.* 2013),
439 although controversial results have been reported for DS, perhaps
440 because of the variability induced by mixed diets, as discussed later
441 (Biondi *et al.* 2008; Cabiddu *et al.* 2019). Such an increase of PUFA
442 content in dairy products is relevant both for the sensory properties of milk
443 and cheese and for human nutrition, as an increase in PUFA intake is
444 considered a preventive factor against cardiovascular diseases. High
445 PUFA content in dairy products has been associated to a less firm and
446 more melting texture and to a greater richness in odour active compounds
447 and sensory descriptors (Hurtaud *et al.*, 2009; Giaccone *et al.*, 2016;
448 Fréтин *et al.*, 2018).

449 *Sensory properties*

450 The evaluation of sensory properties of several diverse dairy and meat
451 products is a scientific challenge, as sensory descriptors are often specific

452 to a single product. The choice of grouping specific and heterogeneous
453 sensory descriptors in sensory families implied an increase in the
454 variability of the dataset. This is particularly the case for different cheese
455 types, as the cheesemaking technology employed is one of the most
456 influential factors for the sensory profile of cheese (Martin *et al.*, 2005).
457 Thus, a substantial loss of the significance of the effect of farming
458 practices was expected. However, several sensory families of dairy and
459 meat products were affected by the inclusion of fresh herbage in animal
460 diets (Table 5). This diet tended ($P < 0.1$) to make the meat more elastic in
461 DS (+18%) than conserved forage, which is consistent with the results of
462 the C18:1cis9/C16:0 ratio and MUFA and PUFA content (Martin *et al.*,
463 2005; Hurtaud *et al.*, 2009; Fréтин *et al.*, 2019). Differences in cheese
464 texture between fresh herbage and conserved forage diets and across
465 cheesemaking processes (Martin *et al.*, 2005; Farruggia *et al.*, 2014) have
466 been well documented in controlled trials. As such, cheese derived from
467 fresh herbage-fed animals is less firm and more elastic and melts more
468 easily. However, the lack of effect on cheese texture under on-farm
469 conditions is not surprising. Cheesemakers can indeed reduce textural
470 variations by adapting curd draining. Conversely, flavour, odour, and taste
471 are more difficult to control, as shown by the differences we observed in
472 these traits under on-farm conditions. In particular, fresh herbage-based
473 diets reduced lactic notes in cheese compared with conserved forage for
474 both DC and DS (-10% and -21%, respectively; Table 5). Under controlled

475 conditions, cheese lactic notes were suppressed with a reduction of fresh
476 herbage proportion of diet in DC and DS (Giaccone *et al.*, 2016;
477 Valdivieso *et al.*, 2016).

478 Fresh herbage inclusion in diet increased vegetal family notes for DC
479 (+30%). Giaccone *et al.* (2016) showed that cheese derived from grazing
480 cattle had more pronounced vegetal notes, which may be related to the
481 high unsaturated FA (UFA) content of cheese. The authors hypothesised
482 that the oxidation of UFA, which have a low oxidative stability, produces
483 several odour-active compounds during cheese ripening, such as
484 alcohols, esters, aldehydes, and ketones, which are associated with
485 vegetal and herbaceous notes. However, Fréтин *et al.* (2019) have
486 proposed a microbial origin of such flavour differences related to fresh
487 herbage inclusion in cattle diets. Fresh herbage increased animal family
488 notes in MS compared with conserved forage (+12%; Table 5). Fresh
489 herbage increased the indole and skatole content of sheep meat
490 compared with conserved forages (Vasta *et al.*, 2006; Schreurs *et al.*
491 2007). Skatole is produced by ruminal bacteria-mediated degradation of
492 tryptophan, and its availability increases with a high protein content and
493 high protein/readily digestible carbohydrate ratio, as in fresh herbage-
494 based diet (Vasta *et al.*, 2006).

495 Intramuscular fat in meat sheep decreased when animals were fed fresh
496 herbage (-31%). A number of intrinsic (age, breed, and sex) and extrinsic
497 factors (pasture quality and physical activity) may contribute to the

498 variation in intramuscular fat deposition (De Brito *et al.*, 2016). According
499 to Gallo *et al.* (2019), the overall lack of concentrates in diet of grazing
500 sheep reduces the availability of propionate at the ruminal level, which is a
501 precursor of glucose and glycogen at the muscular level. Moreover,
502 enhanced lipid mobilisation due to a lower energy intake may favour lean
503 muscle deposition in grazing animals.

504 ***Hay vs. silage***

505 Feeding grass silage instead of hay increased the α -tocopherol content in
506 DC (+10%; Table 6). This may be due to shorter exposure to
507 photodegrading UV light during silage making (Noziere *et al.*, 2006).
508 Furthermore, when herbage is ensiled, it is often harvested at an earlier
509 phenological stage than hay, and the content of α -tocopherol in herbage
510 decreases with herbage maturation, with a pivotal role played by the
511 decreased stem/leaf ratio (Noziere *et al.*, 2006). However, although this
512 decrease was common to all carotenoids, no differences in β -carotene and
513 retinol content were observed between silage and hay. Feeding hay
514 instead of silage increased the content of C18:1trans11 (+19%),
515 CLAcis9trans11 (+18%), and BCFA (+14%), while slightly increasing
516 trends were observed for the C18:3n-3 content and C18:3n-3/C18:2n-6
517 ratio (+17% and +20%, respectively, both $P < 0.1$) (Table 6). These
518 findings corroborate the results obtained under controlled conditions,
519 although the extent of increase under the controlled conditions was higher
520 (between 22% and 48% for all listed FA; Ferlay *et al.*, 2006). The FA

521 profile of milk derived from hay-fed animals was consistent with a higher
522 transfer rate of C18:3n-3 from a hay-based than a silage-based diet
523 (Chilliard *et al.*, 2007). In addition, maize silage was poor in C18:3n-3 but
524 rich in C18:2n-6, which differently affected milk FA profiles depending to
525 the type of silage (grass or maize) fed to the animals.

526 ***Grass silage vs. maize silage***

527 The α -tocopherol and β -carotene content in DC did not differ between
528 maize silage- and grass silage-based diets (Table 7). Although milk
529 derived from animals fed maize silage-based diets is poor in α -tocopherol
530 (Stergiadis *et al.*, 2015; Botana *et al.* 2018), maize silage is often not the
531 exclusive conserved forage under on-farm conditions, and grass silage is
532 also present in non-negligible proportions in cattle diet, particularly in
533 intensive farming systems (Stergiadis *et al.*, 2015). Indeed, Botana *et al.*
534 (2018) showed that diets containing exclusively maize or grass silage as
535 forage led to differences in the vitamin and carotenoid content of milk.

536 Feeding grass silage instead of maize silage decreased the milk content of
537 C16:0 (-4%; $P < 0.1$) and of C18:2n-6 (-9%) but increased in milk content
538 of C18:3n-3 (+34%), CLAcis9trans11 (+24%; $P < 0.1$), PUFA (+7%),
539 BCFA (+15%) as well as the ratio of C18:3n-3/C18:2n-6 (+39%) in DC.
540 The extent of these changes was consistent with findings obtained under
541 controlled trials (Ferlay *et al.*, 2006; Chilliard *et al.*, 2007; Khanal *et al.*
542 2008). Furthermore, maize silage is rich in starch, and a shift in the

543 ruminal population from cellulolytic to amylolytic bacteria reduces the
544 BCFA content of milk (Buccioni *et al.*, 2012).

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

547 Most experiments related to the effects of pasture plant diversity have
548 revealed significant differences in quality traits such as terpenes, FA,
549 carotenoids, and sensory properties (among others Ferlay *et al.*, 2006;
550 Tornambé *et al.*, 2006; Cabiddu *et al.*, 2019; Serrano *et al.*, 2011).
551 However, under on-farm conditions, increasing plant diversity tended to
552 decrease retinol content (-10%; $P < 0.1$) in DC (Table 8). The results for
553 carotenoids are consistent with those for colour.

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

559 Grazing on permanent grasslands with a high plant diversity rather than on
560 temporary grassland with a low diversity reduced the C16:0 content in MS
561 (-11%). Sheep operate a remarkable selection of forage plants to meet
562 their nutritive requirements (Villalba *et al.*, 2011). A greater herbage
563 species diversity in permanent grasslands may promote their selective
564 behaviour toward patches with a high nutritive value and abundant PUFA,

565 thus modifying the FA composition of the ingested diet in the favour of
566 PUFA and decreasing the accumulation of *de novo*-synthesised FA.

567 The high botanical diversity of pastures decreased the SFA content (-4%)
568 but increased the C18:1trans11 (+10%), C18:1cis9/C16:0 (+13%),
569 C18:2n-6 (+10%), C18:3n-3 (+13%), CLAcis9trans11 (+15%), MUFA
570 (+7%), and PUFA (+13%) content and the C18:3n-3/C18:2n-6 (+6%) ratio
571 in DC. It also increased the C18:2n-6 (+10%), C18:3n-3 (+19%),
572 CLAcis9trans11 (+15%), MUFA (+3 %), and PUFA (+15%) content in DS
573 (Table 9). Similar results for these FA have been reported under controlled
574 conditions, albeit at greater extents (between 29 and 53%; Farruggia *et al.*,
575 2014; Cabiddu *et al.*, 2019). The high concentration of unsaturated FA
576 (notably C18:3n-3, C18:2n-6, and their ruminal biohydrogenation
577 intermediates) is consistent with the partial inhibition of ruminal microbial
578 activity by PSMs, which are usually abundant in botanically diverse
579 pasture (Buccioni *et al.*, 2012). Moreover, the greater outflow of PUFA
580 from the rumen as a result of the inhibition of biohydrogenation may have
581 reduced the deposition of C16:0 in MS.

582 Grazing on pastures with a high plant diversity affected the sensory profile
583 of products in DC by increasing their intensity (+10%), spicy (+100%), and
584 animal (+57%; $P < 0.1$) notes (Table 8). These results are particularly
585 relevant as they corroborate some findings observed in controlled trials
586 (Farruggia *et al.*, 2014; Bovolenta *et al.* 2014), although the extent of these
587 changes was much larger under on-farm conditions. This can partially be

588 due to the smaller cheese size and shorter ripening period often applied in
589 controlled trials than in practices on commercial farms. Larger size
590 changes the rind–paste ratio and slows microbial dynamics within a wheel.
591 Indeed, cheeses from pastures with a high botanical diversity require
592 longer ripening periods to fully develop their aromatic potential than those
593 from temporary grassland, allowing differentiation in the sensory profile
594 only after a long ripening period (Agabriel *et al.*, 2004; Farruggia *et al.*,
595 2014).

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

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

609 Overall, we found differences in fewer traits between farming practices
610 than did previous controlled trials. Furthermore, the extent of differences

611 observed here under on-farm conditions was generally lower than that
612 under controlled conditions. Indeed, several confounding factors may be
613 acting on farms, increasing variability and thus weakening the differences
614 observed in controlled trials (Bronkema *et al.*, 2019; Coppa *et al.*, 2019).

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

630 Second, the characteristics of forage fed to animals, particularly of fresh
631 herbage, can significantly affect the extent of differences expected on the
632 quality traits. Advanced phenological stages of herbage decreased the
633 content of C18:1trans 11, CLAcis9trans11, and C18:3n-3 but increased

634 the content of C16:0 in milk (Coppa *et al.*, 2015; Cabiddu *et al.*, 2019). The
635 herbage and milk terpene content increased from the vegetative to
636 flowering stage (Tornambé *et al.*, 2006; Cabiddu *et al.*, 2019), probably
637 affecting the differences expected at the pasture biodiversity level. In
638 addition, grazing selection by animals (Coppa *et al.*, 2011; Coppa *et al.*,
639 2015; Molle *et al.* 2017) may be considered a confounding factor, as it can
640 change according to pasture botanical composition, plant morphology,
641 maturity stage, slope, and grazing management (Coppa *et al.*, 2011;
642 Cabiddu *et al.*, 2017). Under the availability of numerous species at
643 different phenological stages, ruminants are expected to preferably select
644 plants at an earlier developmental stage, which contain low levels of
645 PSMs. Restriction of selection in grazing pastures with a high plant
646 diversity increased the milk monoterpene content by up to 200%
647 (Tornambé *et al.*, 2006). Similarly, the milk SFA content changed by
648 approximately 10% from the beginning to the end of a paddock (Coppa *et*
649 *al.*, 2015). Plant composition can also significantly affect the extent of
650 differences expected in carotenoid and fat-soluble vitamin content of cattle
651 milk (Bovolenta *et al.* 2014), as legumes usually have a lower α -tocopherol
652 content but a higher β -carotene content than grasses (Nozière *et al.*,
653 2006). Herbage terpene content is also highly variable between plant
654 species (Mariaca *et al.*, 1997; Cabiddu *et al.*, 2019), conferring specific
655 terpene fingerprints to dairy products (Bovolenta *et al.*, 2014; Aprea *et al.*
656 2016). Accordingly, single terpenoids may allow for a more robust

657 discrimination than total terpenes between animal products from
658 grasslands with different biodiversity levels (Moran *et al.*, 2019). However,
659 for the same botanical intraspecific variability, this result of terpene profile
660 is valuable only under controlled experimental conditions and cannot be
661 generalised to on-farm conditions. Recently Renna *et al.* (2020) reported
662 an important scientific upgrade on the effect of pasture characteristics on
663 DC. The authors studied the hierarchy of herbage-related factors affecting
664 milk FA composition. However, there is no such study for other quality
665 traits and animal PCs.

666 Finally, another important confounding factor may be the animal
667 characteristics. Even if animal-related factors (e.g. lactation stage, breed,
668 and parity) only marginally affect the quality traits of dairy products, this is
669 not the case for meat (Prache *et al.*, 2020). Animal breed, age, sex, and
670 duration and type of the finishing period affect meat quality. In particular,
671 fattening period duration and initial weight at the beginning of this period
672 affect meat composition and sensory traits in small and large ruminants
673 depending on the animal category (Soulat *et al.*, 2016; De Brito *et al.*,
674 2016). Regarding MS, studies conducted in different regions (both under
675 controlled or on farm conditions) have drawn different conclusions, and
676 their results should be generalised with caution. For instance, young male
677 lambs are almost exclusively destined for a short fattening period in the
678 Mediterranean regions, whereas older sheep of both sexes are
679 slaughtered in Australia. Moreover, different levels of intramuscular fat

680 affect the meat FA profile. In several studies aimed at comparing the
681 effects of different feeding systems on meat FA, the diets offered to the
682 animals were periodically adjusted to achieve comparable growth rates
683 (Luciano *et al.*, 2009; Scerra *et al.*, 2011).

684 **Conclusions**

685 To the best of our knowledge, this is the first quantitative review to
686 investigate the effects of farming practices on a wide array of quality traits
687 (carotenoids, fat-soluble vitamins, colour, FA, terpenes, and sensory
688 properties) of dairy and meat products in cattle and small ruminants. The
689 effects under controlled trials reported in the literature were corroborated
690 on farms only for a part of the addressed quality traits, and when these
691 differences were significant, the extent of effect under on-farm conditions
692 was lower than under controlled conditions. Several confounding factors,
693 for which there is no experimental control when operating on farm, may be
694 the reason of these differences (i.e. mixed diets, phenological stage, and
695 botanical composition of herbage, and animal-related factors). However,
696 differences in several quality traits according to farming practices were
697 confirmed. Specifically, feeding fresh herbage instead of conserved forage
698 to animals affected the quality traits common to several PC, particularly FA
699 composition, probably because of the higher number of studies conducted
700 on farms on these quality traits. It is not surprising that differences
701 between farming practices emerged more frequently for parameters with a
702 higher number of available studies within a PC. However, the high

703 variability in the reference dataset resulting from the pooling of data
704 obtained under heterogeneous conditions on farms could only be partially
705 compensated by the high number of studies included in the statistical
706 analysis. Further studies are required to reinforce the available knowledge
707 on the effect of the studied farming practices: this is the case for meat
708 products (MC in particular) and for all goat products.

709

710 **Ethics approval**

711 Not applicable

712

713 **Data and model availability statement**

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

715

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723 **Author Contribution**

724 A. Cabiddu: validation, data curation, writing - original draft; G. Peratoner:
725 conceptualization, validation, writing - review & editing, supervision; B.
726 Valenti: data curation, writing - original draft; V. Monteils: data curation,
727 writing - original draft; B. Martin: data curation, validation, writing - original
728 draft; M. Coppa: conceptualization, methodology, formal analysis, writing -
729 original draft, writing - review & editing, supervision.

730

731 **Declaration of interest**

732 None

733

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753

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TABLES

981 **Table 1.** Fresh herbage proportion (%DM) in ruminants' diet according to
 982 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)

983 ¹ n, number of data.

984 ² average ± standard deviation (minimum-maximum).

985 ³ PSM, plant secondary metabolites.

986

987 **Table 2.** Effect of feeding fresh herbage instead of conserved forage
 988 and/or concentrates on the carotenoids, fat-soluble vitamins, and terpene
 989 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	***
Retinol	Meat	Sheep	3	5.88	3.39	0.155	**
		Cattle	7	6.88	5.91	0.977	ns
β-Carotene	Dairy	Goat	3	9.17	7.20	0.503	*
		Cattle	18	6.20	4.40	0.579	**
Lutein	Dairy	Cattle	8	0.67	0.41	0.101	*
		Cattle	7	0.10	0.07	0.023	†
Zeaxanthin	Dairy	Cattle	3	12.48	11.32	2.419	ns
		Sheep	5	18.84	17.88	0.289	*
Terpenes tot (ln AAU)	Dairy	Cattle	3	11.22	10.34	2.937	†
		Sheep	5	17.99	16.36	0.33	**
Monoterpenes tot (ln AAU)	Dairy	Cattle	3	11.73	9.67	1.820	ns
		Sheep	5	18.85	10.38	5.170	ns
Sesquiterpenes tot (ln AAU)	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	*
a*	Meat	Cattle	4	11.25	10.80	0.318	ns
		Sheep	8	6.38	6.40	1.088	ns
	Dairy	Cattle	9	-1.85	-2.08	0.693	ns
		Cattle	4	21.95	21.80	0.952	ns
L*	Meat	Sheep	10	13.10	13.24	0.881	ns
		Cattle	9	76.30	76.88	2.590	ns
	Dairy	Cattle	4	39.30	38.10	0.346	†
pH 24h	Meat	Cattle	4	40.65	42.78	1.429	**
		Sheep	10	40.65	42.78	1.429	**
pH 24h	Meat	Sheep	14	5.72	5.72	0.070	ns

990 ¹ n, number of data.

991 ² SEM, standard error of the mean; AAU, arbitrary area units.

992 ³ ***, P < 0.001; **, P < 0.01; *, P < 0.05; †, P < 0.1; ns, not significant.

993

994

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

997

Item ¹	Product category				$\Delta\%$ fresh herbage		N ²	SE ³ model	R ²	Significance (Sign.) ⁴		
	Product	Animal species	Intercept (\pm SE)	Sign.	Covariate coefficient (\pm SE)	Sign.				Product category	$\Delta\%$ fresh herbage	Interaction
Carotenoids and vitamins												
α -Tocopherol	Dairy	Cattle	-9.1 (\pm 6.33)	ns	0.9 (\pm 0.14)	***	20	12.37	0.67	nd	***	nd
β -Carotene	Dairy	Cattle	-26.6 (\pm 9.39)	*	1.8 (\pm 0.21)	***	18	18.85	0.82	nd	***	nd
Fatty acids												
C16:0	Dairy	Cattle	-5.4 (\pm 0.99)	c	-0.2 (\pm 0.02)	***	42	5.39	0.38	***	***	ns
		Goat	2.5 (\pm 1.39)	ab			10					
		Sheep	-3 (\pm 1.19)	bc			25					
C18:1trans11	Dairy	Sheep	5.9 (\pm 3.17)	a	2.1 (\pm 0.22)	***	17	37.78	0.64	ns	***	ns
		Cattle	-22.1 (\pm 11.86)	†			41					
C18:1cis9	Dairy	Sheep	4.3 (\pm 3.42)	*	0.2 (\pm 0.04)	***	24	8.52	0.38	***	**	ns
		Cattle					42					
C18:2n-6	Dairy	Cattle	1.1 (\pm 4.27)	ns	-0.2 (\pm 0.07)	**	26	15.53	0.12	ns	**	ns
		Meat					8					
		Cattle					48					
C18:3n-3	Dairy	Goat			1.1 (\pm 0.13)	***	10	35.93	0.42	ns	***	ns
		Sheep	-8 (\pm 8.58)	ns			26					
		Cattle					8					
CLAcis9trans11	Dairy	Sheep			0.7 (\pm 0.25)	a	19	3672	0.65	ns	***	*
		Cattle	0.7 (\pm 14.3)	ns			53					
		Sheep			0.6 (\pm 0.25)	a	26					*

	Meat	Cattle			0.2 (± 0.13) ^b	ns	8						
SFA	Dairy	Cattle	0 (± 0.54) ^a	ns			50						
		Sheep	-2.4 (± 0.6) ^b	***	-0.1 (± 0.01)	***	25	2.94	0.44	**	***	ns	
	Meat	Cattle	2.4 (± 1.65) ^a	**			8						
MUFA	Dairy	Cattle	-1.3 (± 1.67) ^b	ns			50						
		Sheep	7.9 (± 1.93) ^a	***	0.2 (± 0.04)	***	24	9.99	0.32	**	**	ns	
	Meat	Sheep	-6.6 (± 5) ^b	*			11						
PUFA	Dairy	Cattle					50						
		Goat	-12.4 (± 3.99)	**	0.6 (± 0.07)	***	10	14.6	0.57	ns	***	ns	
C18:1cis9/C16:0	Dairy	Sheep					25						
		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)	**			41						
		Goat	-35 (± 11.41)	**			10						
		Sheep	27.9 (± 8.54)	**	2.1 (± 0.17)	***	26	39.4	0.65	***	***	ns	
	Meat	Cattle	4.9 (± 12.6)	ns			8						
	Meat	Sheep	-21.9 (± 20.77)	*			19						

998 ¹ SFA, sum of straight-chain FA form C4:0 to C24:0, MUFA, sum of monounsaturated FA form C10:1 to C24:1; PUFA, sum of
999 polyunsaturated FA form C18:2 to C22:6.

1000 ² n, number of data.

1001 ³ SE, standard error.

1002 ⁴ ***, P < 0.001; **, P < 0.01; *, P < 0.05; †, P < 0.1; ns, not significant; nd: not determinable.

1003

1004

1005 **Table 4.** Effect of feeding fresh herbage instead of conserved forage
 1006 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
	Dairy	Cattle	41	0.53	0.33	0.036	***
		Goat	10	0.34	0.22	0.036	***
C18:3n-3/C18:2n-6	Meat	Sheep	23	0.64	0.37	0.799	***
		Cattle	8	0.51	0.29	0.050	**
		Sheep	19	0.39	0.18	0.041	***

1007 ¹ SFA, sum of straight-chain FA from C4:0 to C24:0, MUFA, sum of
1008 monounsaturated FA from C10:1 to C24:1; PUFA, sum of polyunsaturated FA
1009 form C18:2 to C22:6, BCFA, sum of branched chain FA from C13:0-iso to C18:0-
1010 iso.

1011 ² n, number of data.

1012 ³ SEM, standard error of the mean.

1013 ⁴ ***, P < 0.001; **, P < 0.01; *, P < 0.05; †, P < 0.1; ns, not significant.

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1015

1016 **Table 5.** Effect of feeding fresh herbage instead of conserved forage
 1017 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	*
Vegetable	Meat	Sheep	6	3.13	3.72	0.517	ns
		Cattle	15	3.25	2.51	0.360	***
Brown	Dairy	Cattle	12	2.19	1.71	0.495	ns
		Cattle	8	2.64	2.23	0.859	ns
Animal	Meat	Sheep	6	5.12	4.50	0.247	**
		Cattle	15	3.00	2.65	0.539	†
Others	Dairy	Cattle	15	3.00	2.65	0.539	†
		Cattle	8	2.02	1.91	0.116	ns
Fattiness	Meat	Cattle	8	2.02	1.91	0.116	ns
		Cattle	4	5.30	5.20	0.058	ns
Juiciness	Meat	Sheep	8	4.37	4.62	0.465	ns
		Sheep	8	4.37	4.62	0.465	ns
Intramuscular fat	Meat	Sheep	8	1.94	2.81	0.370	*

1018 ¹ Sensory properties were grouped under sensory families, as described by
 1019 Piccinali (2012), based on odour, flavour, and taste: intensity, lactic (acid, milk,
 1020 yoghurt, cream, fermented cream, and butter), vegetable (grassy, boiled
 1021 vegetables, garlic, and onion), “brown” (caramel, smoked, sweet, and vanilla),
 1022 animal (animal, stable, barn, and manure), and others (salty, bitter, silage, mould,
 1023 mothball, and cheese mite). Sensory traits data were converted to a common 0–
 1024 10 scale.

1025 ² n, number of data.

1026 ³ SEM, standard error of the mean.

1027 ⁴ ***, P < 0.001; **, P < 0.01; *, P < 0.05; †, P < 0.1; ns, not significant.

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1030 **Table 6.** Effect of feeding hay instead of silage on the quality traits of
 1031 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	†

1032 ¹ SFA, sum of straight-chain FA from C4:0 to C24:0; MUFA, sum of
 1033 monounsaturated FA from C10:1 to C24:1; PUFA, sum of polyunsaturated FA
 1034 form C18:2 to C22:6, BCFA, sum of branched chain FA from C13:0-iso to C18:0-
 1035 iso.

1036 ² n, number of data.

1037 ³ SEM, standard error of the mean.

1038 ⁴ ***, P < 0.001; **, P < 0.01; *, P < 0.05; †, P < 0.1; ns, not significant.

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1042 **Table 7.** Effect of feeding grass silage instead of maize silage on the
 1043 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	*

1044 ¹ SFA, sum of straight-chain FA from C4:0 to C24:0; MUFA, sum of
 1045 monounsaturated FA from C10:1 to C24:1; PUFA, sum of polyunsaturated FA
 1046 form C18:2 to C22:6, BCFA, sum of branched chain FA from C13:0-iso to C18:0-
 1047 iso.

1048 ² n, number of data.

1049 ³ SEM, standard error of the mean.

1050 ⁴ ***, P < 0.001; **, P < 0.01; *, P < 0.05; †, P < 0.1; ns, not significant.

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1052

1053 **Table 8.** Effect of feeding forages from permanent grasslands, botanically
 1054 diversified or rich in plant secondary metabolites (PSM) instead of
 1055 temporary grasslands dominated by grasses on the carotenoids, fat-
 1056 soluble vitamins, and terpene content, colour and sensory properties of
 1057 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 AAU)	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	Meat	Sheep	6	2.97	2.44	0.453	ns
Fattiness	Meat	Sheep	10	2.94	2.98	0.484	ns
Juiciness	Meat	Sheep	10	12.93	10.95	3.845	ns
Juiciness	Meat	Sheep	10	13.39	11.36	3.732	ns

1058 ¹ Sensory properties were grouped under sensory families, as described by
 1059 Piccinali (2012), based on odour, flavour, and taste: intensity, spicy (clover,
 1060 nutmeg, pepper, mint), animal (animal, stable, barn, and manure), and others
 1061 (salty, bitter, silage, mould, mothball, and cheese mite). Sensory traits data were
 1062 converted to a common 0–10 scale.

1063 ² n, number of data.

1064 ³ SEM, standard error of the mean; AAU, arbitrary area units.

1065 ⁴ ***, P < 0.001; **, P < 0.01; *, P < 0.05; †, P < 0.1; ns, not significant.

1066

1067 **Table 9.** Effect of feeding forages from permanent grasslands, botanically
 1068 diversified or rich in plant secondary metabolites (PSM) instead of
 1069 temporary grasslands dominated by grasses on the fatty acid profile of
 1070 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
		Sheep	5	5.74	5.48	0.585	ns
	Meat	Sheep	16	0.90	0.79	0.036	**
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

1071 ¹ SFA, sum of straight-chain FA from C4:0 to C24:0; MUFA, sum of
 1072 monounsaturated FA from C10:1 to C24:1; PUFA, sum of polyunsaturated FA
 1073 form C18:2 to C22:6, BCFA, sum of branched chain FA from C13:0-iso to C18:0-
 1074 iso.

1075 ² n, number of studies.

1076 ³ SEM, standard error of the mean.

1077 ⁴ ***, P < 0.001; **, P < 0.01; *, P < 0.05; †, P < 0.1; ns, not significant.