Characterisation of beef production systems and their effects on carcass and meat quality traits of Piemontese young bulls

(Article begins on next page)

Accepted Manuscript

Characterisation of beef production systems and their effects on carcass and meat quality traits of Piemontese young bulls

Simone Savoia, Alberto Brugiapaglia, Alfredo Pauciullo, Liliana Di Stasio, Stefano Schiavon, Giovanni Bittante, Andrea Albera

Characterisation of beef production systems and their effects on carcass and meat quality traits of Piemontese young bulls

Simone Savoia[1,3,*] simone.savoia@anaborapi.it, Alberto Brugiapaglia[2], Alfredo Pauciullo[2], Liliana Di Stasio[2], Stefano Schiavon[3], Giovanni Bittante[3], Andrea Albera[1]

[1]Associazione Nazionale Allevatori Bovini di Razza Piemontese, Strada Trinità 32/A, 12061 Carrù (CN), Italy

[2]Department of Agricultural, Forest and Food Science, Università degli studi di Torino, Via L. Da Vinci 44, 10095 Grugliasco (TO), Italy

[3]Department of Agronomy, Food, Natural Resources, Animals and the Environment (DAFNAE), Università degli studi di Padova, Viale dell'Università 16, 35020 Legnaro (PD), Italy

*Corresponding author.

Abstract

Using the Piemontese breed as a case study, we characterised beef production systems within the EU classification, and investigated their effects on carcass and meat quality traits. The research involved 1,327 young bulls fattened on 115 farms. The production systems identified by hierarchical cluster analysis were: traditional (restricted feeding and either tie-stalls or loose-housing), modern breeders and fatteners and specialised fatteners (the last two were divided in those using or not using total mixed rations). Despite the large variability in management techniques within production systems, production systems affected ($P < 0.05$) farm size, animal density, environmental scoring, diet, slaughter age and all carcass traits except weight. Lightness (L*) of *Longissimus thoracis* was the only meat quality trait affected ($P < 0.05$), with values greater in the traditional tie-stall system (+0.9 L*). Given the very limited effect of production systems on meat quality traits, factors related to individual animals within farms, such as genetics, should be considered for their improvement.

Keywords: meat colour traits; lightness; tenderness; cooking losses; Piedmontese.

1. Introduction

A study by the European Commission (2011) on the structure of EU beef farms identified three main specialised beef cattle production systems. Suckler cow farmers who produce calves to be sold to other farms for fattening were classified as "breeders", farmers who fatten calves born on their farms were classified as "breeders and fatteners" (B&F), and farmers who purchase weanlings to fatten in their farms were classified as "specialised fatteners".

According to a Farm Accountancy Data Network (FADN) survey, the large majority of European suckler cows are raised in specialised beef operations: 35% by beef breeders and 39% by beef B&F, with the remaining 26% reared on mixed dairy-beef cattle or sheep-beef cattle farms (European Commission, 2011). Only around 50% of male cattle sold at between 1 and 2 years of age are raised on specialised beef farms with specialised fatteners (35%) predominating over B&F (17%). The distribution of suckler cows across farming systems in Italy is similar to that of the EU, whereas specialised beef fatteners have by far the largest share of male cattle marketed at between 1 and 2 years of age (71%) (European Commission, 2011).

In Italy, Piemonte is a suitable case study region because it is the only one that appears on the list of the most important European regions for each of the three beef livestock systems classified by the EU: breeders, B&F and specialised fatteners (European Commission, 2011). Moreover, Piemonte, along with Belgium, obtains the highest prices per male sold, due to their double-muscled breeds: Piemontese and Belgian Blue, respectively.

The Piemontese (Piedmontese) is the most important Italian beef breed, with an overall population of 330,000, including 153,000 cows (Veterinary Information System, 2017), 90% of which are registered in the Italian Piemontese Herd Book (ANABORAPI, 2017).

The beef farming systems in Piemonte are evolving away from very traditional practices (tied animals fed mainly hay and restricted amount of concentrates) to modern ones (loose-housed animals,

51 *ad libitum* feeding and use of total mixed rations [TMR]), and the different systems now coexist

52 (Sgoifo Rossi, Pastorello, Caprarotta, & Compiani, 2011).

53   A few studies have looked at the effects of production system or feeding techniques during the

54 fattening period on carcass and meat quality traits (Daza, Rey, Lopez-Carrasco, & Lopez-Bote, 2014;

55 Avilés, Martínez, Domenech, & Peña, 2015). Other studies have also focused on the possible impact of

56 type of animal management before the fattening period on production and meat quality (Dannenberger,

57 Nuernberg, Nuernberg, & Ender, 2006; Guerrero et al., 2013). However, most of the studies

58 investigated very general effects, such as intensive *vs* extensive systems or concentrate *vs* forage

59 feeding.

60   More recent studies highlighted that individual information on rearing conditions of animals can be

61 exploited with the aim of identifying management techniques affecting carcass and meat quality traits

62 (Gagaoua, Monteils, Couvreur, & Picard, 2017) or to develop predictive models for the same traits

63 (Soulat, Picard, Léger, & Monteils, 2016; Soulat, Picard, Léger, & Monteils, 2018).

64   Currently no detailed analyses of the fattening systems classified as B&F and specialised fatteners,

65 especially in relation to their effects on animal performance and meat quality traits, and particularly

66 with regard to hypertrophic breeds exist.

67   The aim of this study, therefore, was to characterise the beef production systems and assess their

68 effects on carcass and meat quality traits using Piemontese breed as a case study.

69   This knowledge is important for: making a sound economic and technical comparison of the

70 different systems, for predicting future trends in carcass and meat quality trait at population level in the

71 light of the evolution of beef production systems, and for setting future selection goals for genetic

72 improvement of the breed.

73   **2. Material and Methods**

74   This study is part of the "Qualipiem" project, which is aimed at analysing the phenotypic and

75   genetic sources of variation in meat quality traits in the Piemontese breed and at proposing innovative

76   selection strategies for their improvement.

77   **2.1. Farm sampling and data collection**

78   Information on the farms was collected through an interview-based field survey. A total of 115

79   farms in the Piedmont region (north-west Italy) were selected according to the following criteria: they

80   were interested in the aims of the research, their cows were registered in the Piemontese Herd Book

81   (only for B&F farms), they were using, at least in part, artificial insemination, and were delivering their

82   slaughter animals to the largest local cooperative slaughterhouse. Trained technicians visited each farm

83   selected and assisted the farmer in filling out a questionnaire designed to elicit information on farm size

84   (land area in ha and number of fattened animals per year), management practices and animal welfare.

85   Information about management practices included: beef production system (B&F *vs* specialised

86   fatteners), housing system (tie-stalls *vs* loose-housing), feed supply (restricted *vs ad libitum*), feed

87   distribution (TMR *vs* separate distribution of concentrates and forage) and feed composition (as

88   proportions in rations). In order to obtain chemical composition of feeding, analytical information of

89   purchased commercial feeding was registered, whereas for farm produced feedstuffs, chemical

90   composition of feeds used was derived from the chemical analysis of each feed ingredient (Sauvant et

91   al. 2004). The animal welfare information included space allowance (m^2 per head) and assessments of

92   building adequacy, cleanliness, aeration, water availability and animal docility on a scale of 1 to 3

93   (1=insufficient, 2=sufficient, 3=good). Farms were also given an overall evaluation by averaging the

94   above-mentioned scores with the exception of animal docility.

95   The questionnaire was tested before its application for data collection on a sample of farms during

96   the training of technicians.

97   **2.2 Animals and beef sampling**

98   The study was carried out sampling 1,327 Piemontese young bulls progeny of 204 A.I. purebred

99   sires and 1,286 dams, all registered in the Italian Piemontese Herd Book. All the animals were

100   slaughtered at the same commercial abattoir (Operti, Centallo (CN), 12044, Italy) from April 2015 to

101   February 2017. The young bulls were stunned using captive-bolt pistol prior to exsanguination and

102   dressed according to standard commercial practices. Slaughtering was performed in compliance with

103   the Italian welfare regulations and respecting EU regulations (Council Regulation (EC) No.

104   1099/2009). After slaughter, hot carcass weight (CW) and carcass conformation class according to the

105   EU linear grading system (Commission of the European Communities 1982) were recorded. In order to

106   better differentiate carcass conformation, the six main grades (S, E, U, R, O, P, from best to worst)

107   were further divided into three subclasses (+,= or -) as allowed by European Union regulations (Hickey,

108   Keane, Kenny, Cromie, & Veerkamp, 2007). Prior to statistical analysis, the categories of carcass

109   conformation were rearranged into numerical scores (EUS) ranging from 1, corresponding to class "P-

110   ", to 18, corresponding to class "S+". Fatness was not scored in this study as the carcasses of double-

111   muscled breeds are known to be lean and hence exhibit little variation in fatness.

112   Age at slaughter (AS) was calculated from date of birth to date of slaughter. As individual live

113   weights of animals were not available, daily carcass gain (CDG) calculated as the ratio of carcass

114   weight to age at slaughter, was used as measure of young bulls growth rate (Juniper et al., 2005;

115   Boukha et al., 2011).

116   The carcasses were not electrically stimulated and they were chilled at 4 °C until twenty-four hours

117   post-mortem. Twenty-four hours after slaughter, individual samples (4.0 cm thick) of the *Longissimus*

118   *thoracis* (LT) muscle were collected from between the fifth and sixth thoracic vertebrae. The muscle

119   and the excision area were chosen because displayed during the routine slaughterhouse procedures of

120   subdivision of half-carcasses into quarters according to pistol cutting.

121   The beef samples were scanned with a HP Scanjet 5590 Digital Flatbed Scanner (Hewlett-Packard;

122   Palo Alto, California) to obtain images for subsequent measurement of the rib eye area (REA, cm^2). For

123 image calibration, a ruler marked in centimeters was scanned with meat samples. Then, samples were

124 individually vacuum packed and transferred under refrigerated conditions to the laboratory, where they

125 were stored in a chilling room at 4°C for 7 days, after which meat quality traits were measured.

126 **2.3. Analysis of meat quality traits**

127 After ageing (7 days), purge losses (PL) were determined according to the following procedure: the

128 steaks were first weighed in the bag (packaged weight, W1), then after removal from the bag

129 (unpackaged weight, W3), and then the bag was rinsed, dried and weighed (bag weight, W2). PL (%)

130 was calculated as (W1-W2-W3)/(W1-W2) $\times$ 100.

131 Ultimate pH (7 days) was measured with a portable Crison pH-meter PH 25+ (Crison Instruments

132 S.A.; Alella, Barcelona) equipped with a glass electrode Crison 52 32 suitable for meat penetration and

133 an automatic temperature compensator. Before analysis, the pH-meter was calibrated using standard

134 buffers (pH 4.0 and 7.0). The electrodes were inserted approximately 1 cm into the muscle (Boccard et

135 al. 1981).

136 The digital images of the samples were processed with the Image Pro Plus 4.5.1. software (Media

137 Cybernetics, 2001) in order to measure the rib eye area (REA, cm^2). Before each measurement, the

138 image was calibrated with a ruler. The surrounding edge of the sample was automatically traced.

139 However, a manual trace by the operator was added when errors in the automatically trace occurred.

140 Only one experienced operator performed all the measurements.

141 Colour was measured with a Konica Minolta CR-331C colourimeter (Konica Minolta Sensing

142 Americas, Inc; Ramsey, New Jersey) on the freshly-cut surface of each steak after blooming for 1 h at

143 4°C. The CR-331C colourimeter features 45° circumferential illumination/0° viewing geometry, a

144 Ø25mm measuring area and 2° standard observers. The instrument was calibrated on its own white

145 reference tile supplied by the manufacturer and set with the illuminant D65 (colour temperature 6500

146 K), which represents average daylight. CIELAB coordinates (CIE 1976), lightness (L*), redness (a*)

147 and yellowness (b*) were recorded, and hue angle (h*) was calculated as h* = $\tan^{-1}$ (b*/a*), Chroma

148 (C*) as C* = $(a*^2 + b*^2)^{0.5}$. Three random readings were taken at different locations on the meat surface

149 and averaged.

150   After colour measurements had been taken, cooking losses (CL) were determined. Each steak was

151 sealed in a polyethylene bag and cooked in a water bath preheated at 75°C to an internal temperature of

152 70°C. The cooking temperature was monitored with a thermometer inserted into the geometric centre

153 of the steak. When the set temperature was reached, the steak was removed from the water bath and

154 cooled for 30 min under tap water to prevent further cooking. It was then removed from the bag,

155 blotted and reweighed (Honikel, 1998). Cooking Losses (%) were calculated as the weight difference

156 between the raw and the cooked samples as percentage of the weight of the raw meat sample. The

157 steaks used to determine cooking losses were also used for the Warner Bratzler shear force (WBSF) test

158 after overnight chilling at 4°C. Six cylindrical cores of cooked meat 1.27 cm in diameter, taken parallel

159 to the muscle fibres were sheared perpendicularly to the longitudinal orientation of the muscle fibres

160 with a V shaped Warner-Bratzler cutting blade fitted to an Instron 5543 Universal Testing Machine

161 (Instron; Norwood, Massachusetts). WBSF was measured as the maximum force (Newtons) required to

162 shear the cylindrical core at a crosshead speed of 200 mm per min (A.M.S.A., 2015).

163   **2.4. Statistical analyses**

164 **2.4.1. Identification and characterisation of beef production systems**

165   Recent studies (Gagaoua et al., 2017; Soulat et al., 2018) implemented innovative statistical

166 methodologies combining factorial or principal component with cluster analyses for the study of meat

167 quality traits. These methods were able to efficiently categorize animals into management groups and

168 proved to be particularly useful when a very high number of quantitative or qualitative variables were

169 involved. In the present study, the limited number of parameters related to structural and technical

170 features of the investigated farms and the categorical nature of these parameters suggested the authors

171 to perform an agglomerative hierarchical cluster analysis.

172 The systems were then classified by cluster analysis (Lin & Lin, 1994) on the basis of the following

173 four variables: beef production system (B&F *vs* specialised fatteners), housing system (tie-stalls *vs*

174 loose-housing), feed supply (restricted *vs ad libitum*) and feed distribution (TMR *vs* separate

175 distribution of concentrates and forage).

176 A dissimilarity matrix was created with the SAS DISTANCE procedure (2013) using the general

177 dissimilarity coefficient of Gower (1971), an appropriate index for handling nominal, ordinal and

178 (a)symmetric binary data. It was then analysed with the SAS CLUSTER procedure (2013) to create

179 agglomerative hierarchical clusters using Ward's minimum variance method (Murtagh & Legendre,

180 2014). The optimal number of clusters was chosen on the basis of visual inspection, pseudo T-squared

181 (quantification of the difference in the ratio of between-cluster to within-cluster variance by merging

182 clusters), semi-partial R^2 statistics and validate by calculating average silhouette width (Si) criterion

183 (Rousseeuw, 1987; Gagaoua, Picard, Soulat & Monteils, 2018).

184 Land area, number of fattened animals per year, number of fattened animals per ha, and animal

185 welfare traits (space allowance, building, cleanliness, aeration, water supply, animal docility and

186 overall environmental evaluations) were subjected to a one-way ANOVA with the identified production

187 systems as the source of variation. Orthogonal contrasts based on the effects of production system were

188 used to compare general management strategies across the identified systems (tie-stalls *vs* all loose-

189 housing; within loose-housing: traditional restricted *vs* modern *ad libitum* feeding; within modern

190 systems: B&F *vs* fatteners, TMR *vs* separated diet and their interaction).

191 **2.4.2. Statistical analysis of carcass and meat quality traits**

192 The effects of production system on carcass and meat quality traits were assessed on the basis of

193 individual data from the 1,327 young bulls sampled after removing observations falling outside the

194   range of 3 standard deviations from the mean for each trait. Age at slaughter and carcass traits were

195   analysed with the SAS MIXED procedure (2013) adopting the following statistical model:

196

197   y = birth season + parity of dam + production system + farm(production system) + batch + ε

198

199   where y represents the observation of each of the investigated traits; birth season (4 classes: January-

200   March, April-June, July-September, October-December), parity of dam (4 classes: 1st, 2nd, 3rd-8th,

201   >8) and production system are all fixed effects, farm is the random effect of the fattening farm nested

202   within production system (98 levels), batch is the random effect of the day of slaughter (117 levels) and

203   ε is the random residual term. Farms, batch and ε were assumed to be normally and independently

204   distributed $\sim N(0, \sigma^2)$. A minimum cell size of 3 observations was required for both the batch and farm

205   effects.

206   The fixed effect of carcass weight, (5 classes: <350kg, 350-400kg, 401-450kg, 451-500kg, >500kg)

207   was added to the previous model for the analysis of meat quality traits.

208   The effects of different management strategies were evaluated with orthogonal contrasts, whereas

209   comparisons of the least square means of the other fixed effects were performed with a Tukey-Kramer

210   test ($P<0.05$).

211   **3. Results**

212   **3.1. Beef production systems**

213   Six clearly recognizable production systems with a good assignment of farms to groups (best

214   silhouette width criterion S_i=0.73) were identified from the cluster analysis (Table 1). Farms

215   characterised by restricted feeding without the use of TMR were classified as traditional systems, with

216   a distinction made between tie-stall and loose-housing of animals. Modern farms, characterised by

217 loose-housed animals fed *ad libitum*, were divided into B&F or specialised fatteners, each further

218 differentiated according to whether not they used TMR.

219   Traditional farms represented almost 40% of the units surveyed, followed by modern fatteners

220 (33%) and B&F (28%). Nevertheless, almost 41% of the animals sampled came from modern

221 specialised fatteners, 32% from B&F systems and only 27% from traditional farms, reflecting the

222 smaller size of the latter. The distribution of the farms across the criteria used for the cluster analysis

223 allowed us to describe the main characteristics of the beef production systems identified. In half of the

224 farms in the study, cow-calf and fattening operations were integrated, and loose-housing predominated

225 over tie-stalls (77% of farms). The majority of farms (66%) adopted modern a*d libitum* distribution of

226 feed, but only 30% of farms used TMR, probably due to farm size.

227   Comparison of farm size traits across the identified production systems is shown in Table 2. On

228 average, the farms were 39 ha in size, fattened 82 animals per year with a very large variation across

229 herds, and allocated around 5.00 m^2 of space to each fattening animal. The production system affected

230 ($P < 0.05$) all the traits investigated. Traditional farms with tie-stalls were the smallest ($P < 0.05$), with

231 an average size of 27.4 ha. Within the systems adopting loose-housing, traditional systems with

232 restricted feeding were smaller (32.1 ha) ($P < 0.05$) than modern ones. Farms using TMR were the

233 largest ($P < 0.01$), with an average of 51.5 ha for B&F, 58.7 ha for fatteners. As expected, traditional

234 farms with tied animals allocated the least space ($P < 0.01$) to fattening animals at 2.00 m^2 per head.

235 Average space allowance for loose animals was lower ($P < 0.01$) in specialised fattener systems than in

236 B&F systems, reflecting the former's more intensive management and higher ($P < 0.01$) animal density.

237 As a consequence of purchasing calves from other farms, specialised fatteners produced about three

238 times more slaughter animals per year than B&F, despite their similar size in terms of land area.

239   Table 3 shows the effects of production system on some of the indices of animal welfare and

240 environmental conditions. Traditional farms with tie-stalls were the worst overall, with lower ($P <$

241 0.05) scores for all the traits evaluated (not significant only for animal docility). Although the two

242 traditional systems shared certain management features, those with loose-housing were more similar in

243 structural traits to the modern systems. Among the modern systems, overall conditions were better ($P <$

244 0.01) in those using TMR, mainly as a consequence of more modern buildings.

245 Diet compositions in the different production systems are compared in Table 4. Ground corn was

246 the main feed in every system, accounting for between 30 and 40% of the concentrate mix or TMR

247 supplied to fattening animals. Corn silage was very seldom part of the diet in the systems analysed, and

248 even when it was detected (11 of the 115 farms), as in some TMR specialised fattener units, it was

249 never the main component of the diet. Ear corn silage was widely used in TMR systems ($P < 0.01$) and

250 was an important part of the diet, especially in B&F units. Furthermore, in TMR systems, individual

251 feed ingredients were far more widely used than purchased compound feeds ($P < 0.01$). In all the other

252 systems, the use of commercial compound feed was common, with average proportions in the diets

253 ranging from 30% (traditional, pens) to 49% (B&F, without TMR). In the traditional and modern

254 systems that didn't use TMR, hay distributed *ad libitum* was always used as forage, while a mixture of

255 hay and wheat straw was included in the feed in both TMR systems.

256 Table 5 shows the estimated chemical composition of the concentrates supplied in the different beef

257 production systems, expressed as percentage of raw feed. On average, concentrates contained 13%

258 crude protein (CP), 6% crude fibre (CF), 4% ether extract (EE) and 5% ashes (AS). The CP content

259 differed ($P < 0.01$) across production systems, with the lowest proportions found on farms using TMR,

260 probably due to ear corn silage being a substantial component of the diet.

261 **3.2. Carcass and meat quality traits**

262 Descriptive statistics, the ANOVA results and the effects of beef production system on the carcass

263 traits of Piemontese young bulls are presented in Table 6. The average carcass weight of the

264 Piemontese young bulls sampled was 438.1 (±43.6) kg, while the average age at slaughter was 540.9

265 (±63.2) days, giving an average daily carcass gain of 0.818 (±0.107) kg/d. Average EUS was 14.66,

266 corresponding to an average evaluation approaching "E+" in the EU linear grading system.

267 The effect of individual farm within production system explained a proportion of the total variance

268 that varied greatly according to the trait considered, from only about one twentieth in the case of the rib

269 eye area, one tenth for EUS, a quarter for carcass weight and daily carcass gain, to about half for age at

270 slaughter (Table 6), highlighting that the large variability in management techniques still exists even

271 within a given production system. The results show that the batch effect, i.e. animals slaughtered on the

272 same day, explained a much smaller amount of variance than farm, ranging from 4.7% for daily carcass

273 gain to 17.6% for the rib eye area. In the case of the latter trait, it is possible there was an influence of

274 slaughterhouse operator during the sample collection.

275 Production traits (age at slaughter and daily carcass gain), but not carcass quality (EUS and rib eye

276 area), were affected by the young bulls' birth season ($P < 0.01$) (results were most favourable in the

277 January/March season, the least in the April/June season) and the parity of their dam ($P < 0.01$) (the

278 most favourable results were obtained for 3rd-8th parity class).

279 Production system affected age at slaughter ($P < 0.05$), carcass daily gain ($P < 0.01$) and SEUROP

280 ($P < 0.05$). The results for the traditional beef system with tied animals, in particular, were much worse

281 than all the systems with loose-housed animals: tied young bulls grew more slowly ($P < 0.01$) (-0.070

282 kg/d), over a longer ($P < 0.01$) fattening period (+40 d) to reach a similar weight (-10 kg), and their

283 carcasses had lower ($P < 0.01$) muscularity scores (-0.64) and less ($P < 0.05$) rib-eye area (-3.2 cm^2).

284 The production traits of the 5 beef systems rearing loose-housed animals did not differ much, except

285 that the rib-eye of carcasses produced on modern B&F farms had larger ($P < 0.05$) cross-sectional area

286 than those produced by specialised fatteners (+3.2 cm^2).

287 As shown in Tables 7 and 8, colour and meat quality traits were consistently affected by batch,

288 which explained an average of around 30% of total variance, ranging from 14% for PL to 63% for pH,

289 the latter trait characterised by little overall variability. The amount of variance explained by the effect

290   of farm within beef system, instead, was almost negligible, with L* and PL having the highest values at

291   around 7% of total variance.

292   Colour traits, pH and CL were not affected by the young bulls' season of birth nor by the parity of

293   their dams, although both of them had a moderate ($P < 0.05$) influence on PL and the former on shear

294   force ($P < 0.05$).

295   The class of carcass weight was a very important source of variation in all meat quality traits, with

296   the only exception of shear force as the LSMs of the heaviest class were always higher ($P < 0.05$) than

297   those of the lightest.

298   After taking into account the effects of all the other sources of variation included in the model, beef

299   production system was found to have very little influence on the quality traits. In fact, the differences

300   between the production systems were significant only for one of the colour traits, L*. The traditional

301   tie-stall system produces meat with the highest ($P < 0.05$) L* value, probably due to the animals' lack of

302   physical activity, underlined by the contrast between tie-stalls and all loose-housing systems. Feeding

303   was also found to influence ($P < 0.05$) the L* of meat, which was darker from animals fed TMR than

304   from animals fed separated concentrates and hay. We did not find production system to have any

305   influence on pH, shear force and the two water loss traits, PL and CL.

306   **4. Discussion**

307   **4.1. Beef production systems**

308   Few previous studies have directed attention to characterising the farming systems used in beef

309   production. Some recent studies are focused on geographical areas and production techniques far from

310   EU conditions (Asem-Hiablie, Rotz, Stout, & Fisher, 2017; Asem-Hiablie, Rotz, Sandlin, Sandlin, &

311   Stout, 2018; Cavalcante et al., 2018). The use of the Piemontese breed as a case study, allowed to

312   analyse in detail the beef production system in an European context. Due to the characteristics of the

313   present research, the obtained results could be of interest also for other European beef breeds

314 characterised by lean carcasses and for European production systems characterised by intensive
315 fattening.

316   The beef production systems characterised in the present investigation on the basis of a combination
317 of operation cycle, housing and feeding techniques, showed that traditionally managed farms still
318 coexist with more advanced units using modern technologies. B&F and specialised fattener systems are
319 equally represented in our study in terms of both farms and animals. The loose-housing system has
320 been widely adopted, substantiating Sgoifo Rossi et al.'s (2011) findings, which showed an increase in
321 this management system since a previous study on Piemontese breed carried out by Destefanis et al.
322 (2005), who reported an incidence of 56.2%. The structural investments needed for traditional farms
323 with pens to move from tie-stalls to loose-housing allows them to provide their animals with better
324 environmental conditions. Changes in feeding strategies also reveal a tendency towards modernisation:
325 a*d libitum* increased from 46% (Destefanis et al., 2005) to 66% of feed supply system, and TMR was
326 used on 30% of farms against negligible use in previous studies. More advanced type of feed, such as
327 TMR, go hand in hand with a management technique characterised by modern technology and
328 structures. Although fatteners using TMR had the highest density of animals among all the loose-
329 housing systems, their results were the best in most of the subjective environmental evaluations.

330   Concerning feeding, we were unable to compute the exact nutritional composition of the rations, as
331 we did not have any information on the amount of hay and straw distributed *ad libitum* to fattening
332 animals. However, we were able to calculate the nutritional composition of the concentrate mix by
333 deducting the amount of hay and straw from TMR. The average dietary content of crude protein (CP)
334 varied little among production systems, ranging from 133 to 144 g/kg dry matter (DM).

335   Boucqué, Fiems, Cottyn, & Buysse (1984) suggested that a CP content exceeding 140 g/kg DM was
336 required for Belgian Blue young bulls. De Campeneere, Fiems, Cottyn, & Boucqué (1999) suggested a
337 CP concentration decreasing from 163 to 120 g CP/kg of dry matter intake (DMI) for the same breed at
338 different stages of life as a function of the animal's body weight. Reducing the CP content in the diet of

339 purebred Piemontese young bulls from 145 g/kg to 108 g/kg of DMI across the whole fattening cycle

340 was not found to affect growth performance (Schiavon, Tagliapietra, Dal Maso, Bailoni, & Bittante,

341 2010), nor carcass and meat quality traits (Schiavon et al., 2011), but it improved the efficiency of

342 dietary nitrogen use (Schiavon, Tagliapietra, Dalla Montà, Cecchinato, & Bittante, 2012).

343 The crude fibre content of the concentrate mix was also relatively low (6.0±1.6% as fed), especially

344 when the modest level of corn silage and dry roughage included in the rations compared with other

345 beef systems was considered (Cozzi, Mazzenga, Contiero, & Burato, 2008). In assessing the high

346 energy content of the diets used in all the beef production systems studied here, consideration should be

347 given to the very low fat deposition ability of all double-muscled breeds (Fiems, 2012) and the

348 difficulty in reaching the minimal level of carcass fatness required by the beef market.

349 **4.2. Carcass and meat quality traits**

350 Piemontese cattle are highly specialised for beef production as they are double-muscled, a specific

351 mutation of the myostatin gene (mh) located on Chromosome 2 (Grobet et al., 1998), which is almost

352 fixed in this population. Moreover, this breed is heavily selected for improvement in growth rate and

353 carcass conformation (Albera, Mantovani, Bittante, Groen, & Carnier, 2001) and also, unlike the

354 Belgian Blue, for ease of calving (Kizilkaya et al., 2003). Like other double-muscled breeds,

355 Piemontese cattle have large muscular masses and low fat deposition, and reduced incidence of the

356 skeleton, lower feed intake and better feed conversion (Fiems, 2012) than non-double-muscled

357 specialised beef breeds.

358 Average values for carcass traits were consistent with those reported in a previous study on the

359 carcass and meat quality traits of Piemontese young bulls (Boukha et al., 2011). In our study, carcass

360 weight was slightly higher, as was the age at slaughter, hence average daily carcass gain was very

361 similar. The average EUS we obtained, close to the "E+" class, is greater than the "E-" average score

362 reported in the aforementioned study (Boukha et al., 2011) and also had slightly lower variability.

363 There is very little information in the literature on the rib eye area of purebred Piemontese animals. The

364 average value of the rib eye area obtained in the present study was comparable to those reported by

365 Tatum, Gronewald, Seideman, & Lamm (1990) and by Wheeler, Cundiff, Koch, & Crouse (1996) for

366 crossbred Piemontese steers.

367 The quality of meat from double-muscled Piemontese animals meets the requirements of Italian

368 consumers. It has higher water and protein contents and lower levels of intramuscular fat, usually about

369 1% (Barge, Brugiapaglia, Destefanis, & Mazzocco, 1993), than meat from conventional animals while

370 the low collagen content is responsible for its greater tenderness (Destefanis, Barge, & Brugiapaglia,

371 1994). Meat from the Piemontese young bulls and heifers is also in the European Union's register of

372 protected geographical indications (PGI) as "Vitelloni Piemontesi della Coscia" (Reg. no. 703/2017,

373 5th April 2017).

374 The results on meat quality in this study also largely agreed with those reported in previous studies

375 on the Piemontese breed (Boukha et al., 2011; Cecchinato, De Marchi, Penasa, Albera, & Bittante,

376 2011). As in those studies, pH values displayed very small variability and did not exceed 5.87, the

377 value proposed by Page, Wulf, & Schwotzer (2001) as the approximate cut-off between normal and

378 dark-cutting beef carcasses. The average pH value obtained in this study was also very close to those

379 reported by Boukha et al. (2011) for Piemontese young bulls and by Fiems, De Campeneere, Van

380 Caelenbergh, De Boever, & Vanacker (2003) for Belgian Blue bulls.

381 Meat colour results were very similar to those found by Page et al. (2001) from 1,062 beef

382 carcasses, both in terms of average values and variability, but differed from those reported by Boukha

383 et al. (2011) probably due to the different instruments used for colour detection. We obtained lower

384 average values for CL and shear force compared with Destefanis, Brugiapaglia, Barge, & Lazzaroni's

385 (2003) results for Piemontese young bulls and steers, but we found greater variability in both traits, as

386 expected when comparing a large field survey with an experimental trial.

387 **4.3. Effects of carcass weight on meat quality traits**

388 In general, our results revealed a marked effect of carcass weight on colour and meat quality traits.

389 It should be noted that carcass weight is not to be taken as resulting from prolonging or shortening the

390 fattening period of a given young bull, but is rather a measure of young bulls heavier or lighter

391 carcasses. Carcass weight was related to age at slaughter (r = +0.24), but especially to daily carcass

392 gain (r = +0.56), and probably also to dressing percentage and fat deposition. Indeed, young bulls with

393 higher daily carcass gains were of a lower age at slaughter and reached commercial maturity faster.

394 The heavier carcasses were associated with brighter meat resulting from a combination of higher

395 values in all the three colour coordinates. The relationship between carcass weight and L* was reported

396 by Murray (1989), who analysed 7,695 beef carcasses produced in field conditions and found that

397 carcass weight was inversely related to the incidence of dark meat: carcasses weighing less than 272 kg

398 had twice the incidence of dark meat (5.1%) than those weighing more than 318 kg (2.6%).

399 Furthermore, in a study on Charolais, Limousin and dairy-cross animals, Craigie et al. (2010) found

400 that a* and b* were associated with carcass weight.

401 Irrespective of the production system, carcass weight also had a strong effect on most of the other

402 quality traits. We found a significant effect of carcass weight class on pH, but we do not expect any

403 practical implications as the variability in this trait was very small. The water holding capacity of meat

404 tends to be higher in the lighter carcasses. The trend for PL to increase with carcass weight at slaughter

405 may be related to the slower cooling rates in heavier carcasses. Relationships between carcass weight

406 or live weight and tenderness have sometimes been found in experimental studies on the effects of

407 prolonging the duration of fattening. In a study on Charolais heifers, Ellies-Oury et al. (2017) reported

408 a significant effect of slaughter weight on meat tenderness only with older animals, the lower values

409 associated with greater carcass weight, whereas no effect was found with younger animals. Similar

410 results were obtained by Sañudo et al. (2004), who reported that the meat of young bulls slaughtered at

411 550 kg live weight was more tender than that of young bulls slaughtered at 300 kg. In our study,

412 however, tenderness was the only quality trait unaffected by carcass weight.

4.4. Effects of beef production system on carcass traits

Our analyses revealed some unusual aspects as we tried to assess the effects of production system on carcass and beef quality attributes within a single breed, a specific geographical area and relatively homogeneous conditions. All the six production systems identified were characterised by on-farm intensive fattening of animals, large use of cereal-based concentrate feeds and a lack of clear separation between fattening and finishing periods.

In general, we observed a strong effect of production system on all carcass traits except carcass weight. The weight at which animals are slaughtered is determined according to a combination of animal characteristics, such as degree of maturity and body composition, and specific market requirements. With conventional beef breeds and crossbred animals, diet composition and restricted feeding may result in a large variation in fat deposition and, consequently, in the live weight at which optimal carcass fatness is reached. This is not very evident in the case of double-muscled animals (Schiavon & Bittante, 2014), which are not prone to becoming too fat. Weight at slaughter may, therefore, be considered the main target, and the time needed to reach that target is the variable reflecting the degree of efficiency of the production system. The traditional system with tied animals seems to be highly disadvantaged compared with all the beef production systems using loose-housing, as reflected by the lower daily carcass gain, which delays the age at which the animal is slaughtered, and gives rise to a less favourable SEUROP classification and a smaller rib eye area. No significant differences were found between the other beef production systems.

While our analyses were based on field data, most investigations into the effects of management system on production traits have been carried out on experimental stations, often with a small number of animals. A few practices have been compared, such as intensive vs extensive feeding systems (Dannenberger et al., 2006; Guerrero et al., 2013; Daza et al., 2014) or, more specifically, the effects of different diet compositions among conventional breeds (Johnson, Van Horn, West, & Harris, 1992; Avilés et al. 2015). The results obtained were, therefore, then closely related to the design of the

438 experiment rather than answering a need to comply with market requirements. Conversely, a recent

439 study by Soulat et al. (2018) focused on the possibility to predict carcass quality of beef crossbred

440 heifers showing the importance of whole life rearing factors over carcass traits.

441 **4.5. Effects of beef production systems on meat quality traits**

442 In this study, the batch effect explained a large proportion of total variance in meat quality traits,

443 with the exception of pH. As this effect regards animals slaughtered on the same day, it encapsulates

444 the effects of pre-slaughter and slaughter conditions (Adzitey, 2011) and post-mortem handling of

445 carcasses (Warris, 2000). It also includes possible effects of calibration of the equipment used for the

446 physical analyses and of laboratory operators, which are important sources of variation in several meat

447 quality traits. In general, the effects of beef production system and of individual farm within production

448 system on meat quality traits were of a small magnitude. These findings agree with the principles

449 adopted by Meat Standards Australia (MSA) system (Bonny et al., 2018), which puts more focus on

450 slaughter conditions, carcass characteristics, ageing time and cooking techniques than on rearing

451 factors to deliver an eating quality guarantee to consumers.

452 In our study the effect of production systems was appreciable only for L*, reflecting the possible

453 influence of stall and feeding system on meat colour. Our results agree with Brugiapaglia & Destefanis

454 (2012), who found that the meat of tie-stalled Piemontese young bulls had higher L* and b* values than

455 those of animals fattened in pens. Indeed, the darker meat of animals reared in loose conditions could

456 be related with the muscle's greater oxidative capacity resulting from physical activity (Vestergaard,

457 Oksbjerg, & Henckel, 2000; Jurie, Ortigues-Marty, Picard, Micol & Hocquette, 2006). The anatomical

458 position of the muscle and its involvement in movement also play an important role in colour variation

459 (Dunne, O'Mara, Monahan, French, & Moloney, 2005).

460 Regarding feeding system, our study revealed that meat from animals on a TMR diet was associated

461 with lower L* values, resulting in a slightly darker colour, in agreement with the findings of Avilés et

462 al. (2015), who reported that meat from calves fed traditionally was paler than meat from TMR-fed

463 calves, although feeding system did not have a significant effect on the other colour traits. Jurie et al.

464 (2006) highlighted a combined effect of pasture and grass diet *vs*. maize silage-based diet on meat

465 colour, while other studies found no clear relationships between feeding system and meat colour

466 (French et al., 2001; Daza et al., 2014).

467 Apart from colour traits, the scientific literature provides no clear evidence of a relationship

468 between farm management and meat quality. Even when comparison have been made between

469 management systems with greater differences than those examined in this study, such as intensive *vs*

470 extensive fattening, results have often been inconsistent or conflicting. This tendency was also

471 observed in our study where no influence of production system on pH, shear force, PL and CL could be

472 detected. Consistent with our findings, studies by Daza et al. (2014), Cerdeño, Vieira, Serrano, Lavín,

473 & Mantecón (2006) and French et al. (2001) found no effect of feeding system on PL. Guerrero et al.

474 (2013) reported an effect of pre-finishing management of young bulls on PL but not on CL. More

475 recently, Gagaoua et al. (2018) highlighted an effect of carcass fatness over young bulls' meat

476 tenderness, juiciness and flavour. Moreover, they also reported that animals with shorter fattening

477 duration and lower body weight at the beginning of the fattening period were able to produce meat with

478 better eating quality. Soulat et al. (2018) showed that the prediction of meat quality traits obtained from

479 rearing factors were less accurate than those of carcass traits. Nevertheless age at slaughter, ease of

480 birth and genetic potential in muscular development could explain the eating quality of heifers' meat

481 appraised by a tasting panel.

482 **4.6. How carcass and meat quality traits will change in future**

483 As already mentioned in this study, the main change to the beef production systems in the case

484 study area has been the gradual replacement of the traditional system of tied animals with systems

485 using loose-housing. The results obtained here confirm that, aside from improvement in animal welfare

486 and production ethics which are key issues for the European consumers (Hocquette et al., 2018), this

487   trend would greatly improve the animal's production efficiency (daily carcass gain and conformation)

488   without having any undesired effect on meat quality, with the only exception of meat lightness. This

489   goes in the direction of a broader concept relative to a sustainable efficient livestock production, as

490   highlighted by Scollan et al. (2011) and by Hocquette et al. (2018) analysing the future research

491   priorities for animal production. Among the 5 beef systems using loose-housing, there were many

492   differences in terms of number of the manageable animals, capital investments, labour requirements,

493   feeds and welfare issues, with modern systems using TMR fed *ad libitum* being the more efficient.

494   However, the carcass and meat quality traits did not differ much between systems, so no major changes

495   in these traits should be expected in the future as a consequence of changes in farming systems.

496   Within beef production systems, however, there was large variability among individual farms in

497   carcass weight and daily carcass gain, and particularly for age at slaughter, but not for EUS. A great

498   variability among farms was highlighted also in other studies regarding economic and environmental

499   performances (Veysset, Lherm, & Bébin, 2010; Veysset, Lherm, & Bébin, 2011). This variability

500   should be studied in greater detail to understand which factors, not considered in the present study, may

501   be affecting carcass traits and how they could be exploited to improve production efficiency.

502   The small effect of beef production system and of individual farm within beef system makes it clear

503   that the variability in carcass conformation and meat quality traits depends mainly on individual animal

504   factors and that improvements to them can be made by taking action at the level of individual animals.

505   As the most important individual factor explaining meat quality was carcass weight class, it is

506   important to understand the extent to which this effect depends on growth rate potential, fat deposition

507   rate, length of fattening period and carcass yield. As only genetics can yield durable improvements in

508   carcass and meat quality, further knowledge of the genetic mechanisms underlying the variations in

509   these traits also needs to be acquired.

510   **5. Conclusions**

511   This study provides a detailed description of beef production systems using as a case study the

512   Piemontese breed, which exemplifies the main beef production systems classified by the European

513   Union. Six main types, according to specific management strategies were identified. Traditional

514   systems coexist alongside more advanced systems using modern technologies. Within the production

515   systems identified, there is still a considerable variation among farms. Carcass traits are strongly

516   affected by production system, with traditional management conditions having lower production

517   efficiency. However, production system exerts only a very small effect on meat quality, limited to

518   colour traits. It appears that meat quality may be conditioned by other factors related to individual

519   animals within farms, suggesting that future improvement should look, in particular, to genetics.

525   **6. References**

526   Adzitey, F. (2011). Effect of pre-slaughter animal handling on carcass and meat quality. *International*

527   *Food Research Journal*, 18(2), 485-491.

528   Albera, A., Mantovani, R., Bittante, G., Groen, AF., Carnier., P. (2001). Genetic parameters for daily

529   live-weight gain, live fleshiness and bone thinness in station-tested Piemontese young bulls.

530   *Journal of Animal Science,* (72), 449-456.

531   A.M.S.A. (2015). Research guidelines for cookery, sensory evaluation and instrumental tenderness

532   measurements of fresh meat. Champain, Illinois: American Meat Science Association.

533   ANABORAPI (2017). Relazione tecnica e Statistiche [Technical report and statistics]. Carrù (IT):

534   Anaborapi. Available from: www.anaborapi.it.

535   Asem-Hiablie, S., Rotz, C.A., Stout, R.C., & Fisher, K. (2017). Management characteristics of beef

536   cattle production in the western United States. *The Professional Animal Scientist*, (33), 461–

537   471.

538   Asem-Hiablie, S., Rotz, C.A., Sandlin, J.D., Sandlin, M.R., & Stout, R.C. (2017). Management

539   characteristics of beef cattle production in Hawaii. *The Professional Animal Scientist*, (34),

540   167–176.

541   Avilés, C., Martínez, A.L., Domenech, V., & Peña, F. (2015). Effect of feeding system and breed on

542   growth performance, and carcass and meat quality traits in two continental beef breeds. *Meat*

543   *Science,* (107), 94-103.

544   Barge, M.T., Brugiapaglia, A., Destefanis, G., & Mazzocco, P. (1993). The influence of muscle type,

545   ethnic group, muscular hypertrophy on the composition of beef meat. Proceedings of the 39nd

546   international congress of meat science and technology (File S5P02.WP); August 1-6; Calgary,

547   Canada.

548   Boccard, R., Buchter, L., Casteels, E., Cosentino, E., Dransfield, E., Hood, D.E., Joseph, R.L.,

549   MacDougall, D.B., Rhodes, D.N., Schon, L., Tinbergen, B.J., & Touraille, K. (1981).

550   Procedures for measuring meat quality characteristics in beef production experiments, report of

551   a working group in the commission of the European communities (CEC) beef production

552   research programme. *Livestock Production Science,* (8), 385-397.

553   Bonny, S.P.F., O'Reilly, R.A., Pethick, D.W., Gardner, G.E., Hocquette, J.F., & Pannier, L. (2018).

554   Update of Meat Standards Australia and the cuts based grading scheme for beef and sheepmeat.

555   *Journal of Integrative Agriculture*, 17, 1641–1654.

556 Boucqué, Ch.V., Fiems, L.O., Cottyn, B.G., & Buysse, F.X. (1984). Besoin en protéines de taureaux
557   culards au cours de la période de finition [Protein needs of hypertrophic bulls during finishing
558   period]. *Revue de Agriculture,* (37), 661–670.

559 Boukha, A., Bonfatti, V., Cecchinato, A., Albera, A., Gallo, L., Carnier, P., & Bittante, G. (2011).
560   Genetic parameters of carcass and meat quality traits of double muscled Piemontese cattle.
561   *Meat Science,* (89), 84-90.

562 Brugiapaglia, A., & Destefanis, G. (2012). Influence of the housing system on meat quality of double
563   muscled Piemontese young bulls. *Livestock Science,* (147), 73-78.

564 Cavalcante, D.H., Campelo, J.E.G., Santos, N.P.S., Ferreira, R.R., Fonseca, W.J.L., & Evangelista, A.F.
565   (2018). characterisation of beef cattle farming and the perspective for implementation of
566   traceability. *Acta Scientiarium, Animal Science* [online], (40), e36282.

567 Cecchinato, A., De Marchi, M., Penasa, M., Albera, A., & Bittante, G. (2011). Near-infrared reflectance
568   spectroscopy predictions as indicator traits in breeding programs for enhanced beef quality.
569   *Journal of Animal Science,* (89), 2687-2695.

570 Cerdeño, A., Vieira, C., Serrano, E., Lavín, P., & Mantecón, A.R. (2006). Effects of feeding strategy
571   during a short finishing period on performance, carcass and meat quality in previously-grazed
572   young bulls. *Meat Science,* (72), 719-726.

573 CIE. 1976. Commission Internationale de l'Éclairage. Recommendations on uniform colour spaces-
574   colour difference equations, psychometric colour terms. Supplement no. 2 to CIE publication
575   No. 15 (E-1.3.1.) 1978, 1971/(TC-1.3.) Commission Internationale de l'Éclairage Paris, France.

576 Commission of the European Communities. 1982. Commission of the European Communities (Beef
577   Carcass Classification) Regulations. Council Regulations 1358/80, 1208/81, 1202/82.
578   Commission Regulations 2930/81, 563/82, 1557/82. Brussels: Commission of the European
579   Communities.

Cozzi, G., Mazzenga, A., Contiero, B., & Burato, G. (2008). Use of maize silage in beef cattle feeding during the finishing period. *Italian Journal of Animal Science,* (7), 39-52.

Craigie, C., Ross, D., Maltin, C., Purchas, R., Morris, S., & Roehe R. (2010). The relationship between beef quality and carcass quality attributes measured under commercial conditions. *Advances in Animal Biosciences,* (1), 129-129.

Dannenberger, D., Nuernberg, K., Nuernberg, G., & Ender, K. (2006). Carcass and meat quality of pasture vs concentrate fed German Simmental and German Holstein bulls. *Archives Animal Breeding,* (49), 315-328.

Daza, A., Rey, A.I., Lopez-Carrasco, C., & Lopez-Bote, C.J. (2014). Influence of feeding system on growth performance, carcass characteristics and meat and fat quality of Avileña-Negra Ibérica calves' breed. *Spanish Journal of Agricultural Research,* (12), 409-418.

De Campeneere, S., Fiems, L.O., Cottyn, B.G., & Boucqué, C.V. (1999). Phase feeding to optimize performance and quality of Belgian Blue double-muscled bulls. J*ournal of Animal Science,* (69), 275–285.

Destefanis, G., Barge, M.T., & Brugiapaglia, A. (1994). pH, colour and water holding capacity in muscles of young bulls differing for ethnic group. *Proceedings of the 40th international congress of meat science and technology* (File S-IVA.25), August 28–September 2; The Hague, Netherlands.

Destefanis, G., Brugiapaglia, A., Barge, M.T., & Lazzaroni, C. (2003). Effect of castration on meat quality in Piemontese cattle. *Meat Science,* (64), 215-218.

Destefanis, G., DiStasio, L., Brugiapaglia, A., Barbera, S., Tassone, S., Bassanino, M., Franco, G., & Bosticco, A. (2005). Patrimonio zootecnico del Piemonte, la razza bovina Piemontese [Heritage livestock of Piemonte, Piemontese breed]. Torino (IT): agricoltura&ricerca. Chapter 1, La razza bovina Piemontese, la filiera produttiva [Piemontese breed, the production chain]; p:19-30.

604   Dunne, P.G., O'Mara, F.P., Monahan, F.J., French, P., & Moloney, A.P. (2005). Colour of muscle from

605   18-month-old steers given long term daily exercise. *Meat Science,* (71), 212-229.

606   Ellies-Oury, M.P., Dumont, R., Perrier, G., Roux, M., Micol, D., & Picard, B. (2017). Effect of age and

607   carcass weight on quality traits of m. rectus abdominis from Charolais heifers. *Animal,* (11),

608   720–727.

609   European Commission, Directorate-General for Agriculture and Rural Development. 2011. EU beef

610   farms report 2010 based on FADN data.

611   Fiems, L.O. (2012). Double Muscling in Cattle: Genes, Husbandry, Carcasses and Meat. *Animal,* (2),

612   472-506.

613   Fiems, L.O., De Campeneere, S., Van Caelenbergh, W., De Boever, J.L., & Vanacker, J.M. (2003).

614   Carcass and meat quality in double-muscled Belgian Blue bulls and cows. *Meat Science,* (63),

615   345–352.

616   French, P., O'Riordan, E.G., Monahan, F.J., Caffrey, P.J., Mooney, M.T., Troy, D.J., & Moloney, A.P.

617   /(2001). The eating quality of meat from steers fed grass and/or concentrate. *Meat Science,* (57),

618   379-386.

619   Gagaoua, M., Picard, B., Soulat, J., & Monteils, V. (2018). Clustering of sensory eating qualities of

620   beef: Consistencies and differences within carcass, muscle, animal characteristics and rearing

621   factors. *Livestock Science*, (214), 245–258.

622   Gagaoua, M., Monteils, V., Couvreur, S., & Picard, B. (2017). Identification of Biomarkers Associated

623   with the Rearing Practices, Carcass Characteristics, and Beef Quality: An Integrative Approach.

624   *Journal of Agricultural and Food Chemistry*, (65), 8264−8278.

625   Gower, J.C. (1971). A general coefficient of similarity and some of its properties. *Biometrics,* (27), 857-

626   874.

627 Grobet, L., Poncelet, D., Royo, L.J., Brouwers, B., Pirottin, D., Michaux, C., Menissier, F., Zanotti, M.,

628   Dunner, S., & Georges, M. (1998). Molecular definition of an allelic series of mutations

629   disrupting the myostatin function and causing double-muscling in cattle. *Mammalian*

630   *Genome*,(9), 210-213.

631 Guerrero, A., Sañudo, C., Albertí, P., Ripoll, G., Campo, M.M., Olleta, J.L., Panea, B., Khliji, S., &

632   Santolaria, P. (2013). Effect of production system before the finishing period on carcass, meat

633   and fat qualities of beef. *Animal,* (7), 2063-2072.

634 Hickey, J.M., Keane, M.G., Kenny, D.A., Cromie, A.R., & Veerkamp, R.F. (2007). Genetic parameters

635   for EUROP carcass traits within different groups of cattle in Ireland. *Journal of Animal*

636   *Science*,(85), 314-321.

637 Hocquette, J.F., Ellies-Oury, M.P., Lherm, M., Pineau, C., Deblitz, C., & Farmer, L. (2018). Current

638   situation and future prospects for beef production in Europe - A review. *Asian-Australasian*

639   *Journal of Animal Sciences*, (31), 1017–1035.

640 Honikel, KO. (1998). Reference methods for assessment of physical characteristics of meat. *Meat*

641   *Science,* (49), 447-457.

642 Jurie, C., Ortigues-Marty, I., Picard, B., Micol, D., & Hocquette, J.F. (2006). The separate effects of the

643   nature of diet and grazing mobility on metabolic potential of muscles from Charolais steers.

644   *Livestock Science*, (104), 182–192.

645 Johnson, D.D., Van Horn, H.H., West, R.L., & Harris, B.J.R. (1992). Effect of calf management on

646   carcass characteristics and palability traits of Veal Calves. *Journal of Dairy Science,* (75), 2799-

647   2804.

648 Juniper, D.T., Browne, E.M.,Fisher, A.V., Bryant, M.J., Nute, G.R., & Beever, D.E. (2005). Intake,

649   growth and meat quality of steers given diets based on varying proportions of maize silage and

650   grass silage. *Animal Science,* (81):159-170.

651 Kizilkaya, K., Carnier, P., Albera, A., Bittante, G, Tempelman, RJ. (2003). Cumulative t-link threshold

652   models for the genetic analysis of calving ease scores. *Genetics Selection Evolution*, (35), 489-

653   512.

654 Lin, C.Y., & Lin, C.S. (1994). Investigation of genotype-environment interaction by cluster analysis in

655   animal experiments. *Canadian Journal of Animal Science,* (74), 607-612.

656 Murray, A.C. (1989). Factors affecting beef colour at time of grading. *Canadian Journal of Animal*

657   *Science,* (69), 347-355.

658 Murtagh, F. & Legendre, P. (2014). Ward's Hierarchical Agglomerative Clustering Method: Which

659   Algorithms Implement Ward's Criterion? *Journal of Classification*, (31), 274-295.

660 Page, J.K., Wulf, D.M., & Schwotzer, T.R. (2001). A survey of beef muscle colour and pH. J*ournal of*

661   *Animal Science,* (79), 678-687.

662 Rousseeuw, P.J. (1987). Silhouettes: a graphical aid to the interpretation and validation of cluster

663   analysis. J. Comput. Appl. Math. 20, 53–65.

664 SAS. (2013). Statistical Analysis System Proprietary Software. Release 9.4. SAS Institute Inc., Cary,

665   NC, USA.

666 Sañudo, C., Macie, E.S., Olleta, J.L., Villarroel, M., Panca, B., & Albertì, P. (2004). The effects of

667   slaughter weight, breed type and ageing time on beef meat quality using two different texture

668   devices. *Meat Science,* (66), 925-932.

669 Sauvant, D., Perez, J.M., & Tran, G. (2004). Tables of Composition and Nutritional Value of Feed

670   Materials: Pigs, Poultry, Cattle, Sheep, Goats, Rabbits, Horses and Fish. INRA Editions,

671   Versailles, France.

672 Schiavon, S., Tagliapietra, F., Dal Maso, M., Bailoni, L., & Bittante, G. (2010). Effects of low-protein
673   diets and rumen-protected conjugated linoleic acid on production and carcass traits of growing
674   double-muscled Piemontese bulls. *Journal of Animal Science,* (88), 3372–3383.

675 Schiavon, S., De Marchi, M., Tagliapietra, F., Bailoni, L., Cecchinato, C., & Bittante, G. (2011). Effect
676   of high or low protein ration combined or not with rumen protected conjugated linoleic acid
677   (CLA) on meat CLA content and quality traits of double-muscled Piemontese bulls. *Meat*
678   *Science,* (89), 133–142.

679 Schiavon, S., Tagliapietra, F., Dalla Montà, G., Cecchinato, A., & Bittante, G. (2012). Low protein diets
680   and rumen-protected conjugated linoleic acid increase nitrogen efficiency and reduce the
681   environmental impact of double-muscled young Piemontese bulls. *Animal Feed Science*
682   *Technology,* (174), 96–107.

683 Scollan, N.D., Greenwood, P.L., Newbold, C.J., Yáñez Ruiz, D.R., Shingfield, K.J., Wallace, R.J. &
684   Hocquette, J.F. (2011). Future research priorities for animal production in a changing world.
685   *Animal Production Science*, (51), 1–5.

686 Sgoifo Rossi, C.A., Pastorello, G., Caprarotta, L., & Compiani, R. (2011). Piemontese, se c'è unifeed è
687   più alto il peso carcassa [Piemontese, heavier carcass weight with total mixed ration].
688   *Informatore Zootecnico,* (1), 22-29.

689 Sistema Informativo Veterinario [Veterinary Information System]. 2017. Teramo (IT): Ministero della
690   Salute; [accessed 17 Jan 2018]. http://www.vetinfo.sanita.it

691 Soulat, J., Picard, B., Léger, S., & Monteils, V. (2016). Prediction of beef carcass and meat traits from
692   rearing factors in young bulls and cull cows. Journal of Animal Science, (94), 1712–1726.

693 Soulat, J., Picard, B., Léger, S., & Monteils, V. (2018). Prediction of beef carcass and meat quality
694   traits from factors characterising the rearing management system applied during the whole life
695   of heifers. *Meat Science,* (140), 88-100.

696   Tatum, J.D., Gronewald, K.W., Seideman, S.C., & Lamm, W.D. (1990). Composition and quality of
697   beef from steers sired by Piedmontese, Gelbvieh and Red Angus bulls. *Journal of Animal*
698   *Science,* (68), 1049-1060.

699   Vestergaard, M., Oksbjerg, N., & Henckel, P. (2000). Influence of feeding intensity, grazing and
700   finishing feeding on muscle fibre characteristics and meat colour of semitendinosus,
701   longissimus dorsi and supraspinatus muscles of young bulls. *Meat Science,* (54), 177-185.

702   Veysset, P., Lherm M., & Bébin, D. (2010). Energy consumption, greenhouse gas emissions and
703   economic performance assessments in French Charolais suckler cattle farms: Model-based
704   analysis and forecasts. *Agricultural Systems*, (103), 41–50.

705   Veysset, P., Lherm M., & Bébin, D. (2011). Productive, environmental and economic performances
706   assessments of organic and conventional suckler cattle farming systems. *Organic Agriculture*,
707   (1), 1–16.

708   Warris, P.D. (2000). Meat science: an introductory text. Wallingford (UK): CABI Publisher. Chapter 8,
709   Post-mortem handling of carcasses and meat quality; p. 156-181.

710   Wheeler, T.L., Cundiff, L.V., Koch, R.M., & Crouse, J.D. (1996). characterisation of Biological Types
711   of Cattle (Cycle IV): Carcass Traits and Longissimus Palatability. *Journal of Animal Science,*
712   (74), 1023-1035.

Table 1. Profiles of beef production systems identified by hierarchical cluster analysis on the basis of the following binary variables: beef production system (Breeders&fatteners *vs* specialised fatteners), housing system (tie-stalls *vs* loose-housing), feed supply (restricted *vs ad libitum*) and feed distribution (TMR *vs* separate distribution of concentrates and forage).

Cluster	Sampled (n):		Incidence on farms (%)			
	Farms	Young bulls	Integrated cow-calf and fattening	Ad libitum feeding (ad lib)	Total Mixed Ration (TMR)	Loose housing system (pens)
All farms	115	1,327	50	66	30	77
Traditional systems[a]						
Tie-stalls	24	160	63	25	0	0
Pens	21	196	48	0	19	100
Breeders-fatteners, *ad lib*:						
TMR	14	218	100	100	100	100
No TMR	18	208	100	100	0	100
Fatteners, *ad lib*:						
TMR	16	200	0	100	100	88
No TMR	22	345	0	100	0	100

[a]Adopting restricted feeding.

718 **Table 2.** Descriptive statistics and effect of beef production system on farm size, yearly production and
719 space allowance of animals.

	Farm size, ha	Slaughtered animals, $n \times ha^{-1}$	Slaughtered animals, $n \times yr^{-1}$	Space allowance, $m^2 \times head^{-1}$
General mean	39.2	2.55	82.3	4.66
Standard deviation	26.4	4.20	111.5	2.44
Traditional systems[a]				
Tie-stalls	27.4	1.77	46.0	2.00
Pens	32.1	1.92	63.9	5.20
Breeder-fatteners, *ad lib*:				
TMR[b]	51.5	1.41	59.6	6.20
No TMR[b]	44.0	0.83	34.8	6.01
Fatteners, *ad lib*:				
TMR[b]	58.7	3.76	163.7	4.62
No TMR[b]	33.7	5.43	137.0	5.00
Contrasts (estimate):				
Tie-stall *vs* loose-housing[1]	-13.0*	-0.62	-27.8	-3.60**
Restricted *vs* ad lib[2]	-14.9*	-0.94	-34.9	-0.25
Breeders-fattener *vs* fatteners[3]	1.5	-3.48**	-103.1**	1.30**
TMR[b] *vs* no TMR[b,4]	16.3**	-0.54	25.7	-0.10
Interaction[5]	8.8	-1.12	0.9	-0.29
RMSE	24.6	3.97	103.3	2.00

720 [a]Restricted feeding
721 [b]Total mixed ration
722 *$P<0.05$.
723 **$P<0.01$.
724 [1]Traditional tie-stalls *vs* (Traditional tie-stalls + breeders-fatteners-noTMR + breeders-fatteners-TMR +
725 fatteners-noTMR + fatteners-TMR)
726 [2]Traditional pens *vs* (breeders-fatteners-noTMR + breeders-fatteners-TMR + fatteners-noTMR +
727 fatteners-TMR)
728 [3](breeders-fatteners-noTMR + breeders-fatteners-TMR) *vs* (fatteners-noTMR + fatteners-TMR)
729 [4](breeders-fatteners-noTMR + fatteners-noTMR) *vs* (breeders-fatteners-TMR + fatteners-TMR)
730 [5](breeders-fatteners-TMR + fatteners-noTMR) *vs* (breeder-fatteners-noTMR + breeders-TMR)

731 **Table 3.** Descriptive statistics and effect of beef production system on subjective evaluation of animal
732 facilities by technicians (1=poor, 2=average, 3=good).

	Building adequacy	Cleanness condition	Aeration efficiency	Water availability	Animal docility	Overall evaluation
General mean	2.11	2.16	2.04	2.73	2.78	2.29
Standard deviation	0.75	0.65	0.77	0.52	0.46	0.52
Traditional systems[a]						
Tie-stalls	1.38	1.79	1.42	2.54	2.62	1.81
Pens	2.14	1.95	2.10	2.52	2.71	2.20
Breeder-fatteners, *ad lib*:						
TMR[b]	2.43	2.29	2.43	3.00	2.93	2.56
No TMR[b]	2.06	2.33	2.22	2.72	2.89	2.35
Fatteners, *ad lib*:						
TMR[b]	2.73	2.47	2.47	2.93	2.87	2.69
No TMR[b]	2.29	2.33	2.00	2.81	2.76	2.39
Contrasts (*estimate*):						
Tie-stall *vs* loose-housing[1]	-0.85**	-0.45**	-0.77**	-0.22*	-0.20	-0.56**
Restricted *vs ad lib*[2]	-0.23	-0.40**	-0.18	-0.34**	-0.15	-0.29**
Breeders-fattener *vs* fatteners[3]	-0.27	-0.09	0.09	-0.01	0.09	-0.08
TMR[b] *vs* no TMR[b,4]	0.41**	0.04	0.34	0.20	0.07	0.26*
Interaction[5]	0.04	0.09	0.13	-0.08	0.03	0.04
RMSE	0.62	0.61	0.70	0.50	0.45	0.44

733 [a]Restricted feeding
734 [b]Total mixed ration
735 *P<0.05.
736 **P<0.01
737 [1]Traditional tie-stalls *vs* (Traditional tie-stalls + breeders-fatteners-noTMR + breeders-fatteners-TMR +
738 fatteners-noTMR + fatteners-TMR)
739 [2]Traditional pens *vs* (breeders-fatteners-noTMR + breeders-fatteners-TMR + fatteners-noTMR +
740 fatteners-TMR)
741 [3](breeders-fatteners-noTMR + breeders-fatteners-TMR) *vs* (fatteners-noTMR + fatteners-TMR)
742 [4](breeders-fatteners-noTMR + fatteners-noTMR) *vs* (breeders-fatteners-TMR + fatteners-TMR)
743 [5](breeders-fatteners-TMR + fatteners-noTMR) *vs* (breeder-fatteners-noTMR + breeders-TMR)

744 **Table 4.** Effect of beef production system on ingredient composition (% as fed) of concentrate mix and
745 type of forage supply.

	Composition (% as fed) of concentrate mix given separately or mixed with hay in TMR:											Forages supplied
	Corn silage	Ear corn silage	Compound feed	Ground corn	Barley, wheat	Wheat bran[1]	Beet pulp	Soybean meal	Other proteins	Fats	M-V mix	
General mean	2.27	8.90	34.12	34.95	2.72	5.89	3.14	5.42	1.14	0.38	0.87	-
Standard deviation	8.37	21.07	37.22	23.95	5.53	7.57	5.18	6.63	3.31	0.92	1.39	-
Traditional systems[a]:												
Tie-stalls	1.75	2.29	48.58	30.71	5.28	6.58	0.42	3.25	0.92	-	0.25	*ad lib*
Pens	1.07	7.89	30.52	39.30	2.30	7.14	3.84	5.35	1.56	0.19	0.83	*ad lib*
Breeder-fatteners, *ad lib*:												
TMR[b]	1.79	32.50	10.51	33.53	1.22	4.53	4.39	9.90	-	0.56	1.08	12.6[2]
No TMR[b]	-	-	48.72	38.22	1.94	3.06	3.22	2.44	1.22	0.33	0.72	*ad lib*
Fatteners, *ad lib*:												
TMR[b]	8.94	18.99	12.19	34.00	1.16	7.45	4.27	7.59	1.78	1.14	1.43	12.2[3]
No TMR[b]	1.27	2.00	40.80	34.37	3.06	6.01	3.75	5.87	1.18	0.35	1.18	*ad lib*
Contrasts (*estimate*):												
Tie-stall *vs* loose-housing[1]	0.72	8.30	15.94*	-5.64	3.15*	1.40	-3.38	-2.64	-0.07	-0.36	-0.71*	-
Restricted *vs* ad lib[2]	-1.93	-5.51	2.47	4.27	0.46	1.88	-0.07	-1.10	0.51	-0.41	-0.27	-
Breeders-fattener *vs* fatteners[3]	-4.21*	5.76	3.12	1.69	-0.53	-2.94	-0.20	-0.56	-0.87	-0.30	-0.40	-
TMR[b] *vs* no TMR[b,4]	4.73*	24.7**	-33.41**	-2.53	-1.31	1.45	0.84	4.59**	-0.31	0.50*	0.30	-
Interaction[5]	2.94	-7.76	4.80	2.17	-0.59	-0.01	-0.32	-2.87	0.91	0.28	-0.06	-
RMSE	8.09	18.58	34.84	24.29	5.45	7.59	5.08	6.34	3.34	0.87	1.37	-

746   [a]Restricted feeding
747   [b]Total mixed ration
748   [1]Included other cereal byproducts and distillers and soybean hulls
749   [2]% of total intake (on average 87.1% meadow hay and 12.9% barley or wheat straw)
750   [3]% of total intake (on average 86.2% meadow hay and 13.8% barley or wheat straw)
751   *P<0.05.
752   **P<0.01
753   [1]Traditional tie-stalls *vs* (Traditional tie-stalls + breeders-fatteners-noTMR + breeders-fatteners-TMR +
754 fatteners-noTMR + fatteners-TMR)
755   [2]Traditional pens *vs* (breeders-fatteners-noTMR + breeders-fatteners-TMR + fatteners-noTMR +
756 fatteners-TMR)
757   [3](breeders-fatteners-noTMR + breeders-fatteners-TMR) *vs* (fatteners-noTMR + fatteners-TMR)
758   [4](breeders-fatteners-noTMR + fatteners-noTMR) *vs* (breeders-fatteners-TMR + fatteners-TMR)
759   [5](breeders-fatteners-TMR + fatteners-noTMR) *vs* (breeder-fatteners-noTMR + breeders-TMR)

760 **Table 5.** Descriptive statistics and effect of beef production system on nutrient composition of mix
761 concentrates (% as fed). TMR[b] net of forages amount.

	Crude protein	Crude fibre	Ether extract	Ashes
General mean	13.1	6.0	3.9	4.79
Standard deviation	1.8	1.6	1.0	1.4
Traditional systems[a]				
Tie-stalls	13.6	6.1	3.5	4.7
Pens	13.3	5.7	3.6	4.4
Breeder-fatteners, *ad lib*				
TMR[b]	12.8	5.9	3.6	4.1
No TMR[b]	13.6	6.1	4.2	6.0
Fatteners, *ad lib*				
TMR[b]	11.9	6.2	3.9	4.1
No TMR[b]	13.5	5.8	4.2	5.2
Contrasts (*estimate*)				
Tie-stall *vs* loose-housing[1]	0.3	0.2	-0.4	-0.3
Restricted *vs ad lib*[2]	0.3	-0.3	-0.4	-0.5
Breeders-fattener *vs* fatteners[3]	0.5	0.0	-0.1	0.4
TMR[b] *vs* no TMR[b,4]	-1.2**	0.0	-0.4	-1.5**
Interaction[5]	-0.4	0.2	0.2	0.4
RMSE	1.7	1.7	1.0	1.3

762 [a]Restricted feeding
763 [b]Total mixed ration
764 *$P<0.05$.
765 **$P<0.01$.
766 [1]Traditional tie-stalls *vs* (Traditional tie-stalls + breeders-fatteners-noTMR + breeders-fatteners-
767 TMR + fatteners-noTMR + fatteners-TMR)
768 [2]Traditional pens *vs* (breeders-fatteners-noTMR + breeders-fatteners-TMR + fatteners-noTMR +
769 fatteners-TMR)
770 [3](breeders-fatteners-noTMR + breeders-fatteners-TMR) *vs* (fatteners-noTMR + fatteners-TMR)
771 [4](breeders-fatteners-noTMR + fatteners-noTMR) *vs* (breeders-fatteners-TMR + fatteners-TMR)
772 [5](breeders-fatteners-TMR + fatteners-noTMR) *vs* (breeder-fatteners-noTMR + breeders-TMR)

773 **Table 6.** Descriptive statistics, ANOVA, and effects of beef production system on age of
774 Piemontese young bulls at slaughter and carcass traits.

	Age at slaughter d	Carcass weight kg	Carcass gain kg/d	SEUROP score[1]	Rib eye area cm^2
General mean	541	438	0.818	14.66	92.0
Standard deviation	63	44	0.107	1.54	14.3
ANOVA					
Slaughter batch[2] (%)	7.1	8.9	4.7	6.8	17.6
Farm within system[2] (%)	52.5	24.7	27.3	10.2	4.9
Birth season (*F-value*)	13.4**	1.6	4.5**	1.2	0.9
Parity of dam (*F-value*)	7.0**	2.7*	10.9**	0.8	0.4
Beef production system (*F-value*)	3.1*	0.6	4.8**	3.1*	2.3
Beef production system (*LS-means*)					
Traditional systems#:					
Tie-stalls	581	426	0.746	14.02	89.5
Pens	539	434	0.815	14.40	91.0
Breeder-fatteners, *ad lib*:					
TMR^ç	559	438	0.797	14.92	94.6
No TMR^ç	515	432	0.849	14.62	92.8
Fatteners, *ad lib*:					
TMR^ç	549	430	0.789	14.46	89.0
No TMR^ç	550	438	0.803	14.69	92.2
Contrasts (*estimate*):					
Tie-stall *vs* loose-housing[1]	40**	-10	-0.070**	-0.64**	-3.2*
Restricted *vs ad lib*[2]	-4	2	0.005	-0.28	-1.2
Breeders-fattener *vs* fatteners[3]	-13	1	0.027	0.20	3.1*
TMR^ç *vs* no TMR^{ç}[4]	21	-1	-0.033	0.04	-0.7
Interaction[5]	-22	-7	0.019	-0.27	-2.5
RMSE	42.1	36.1	0.087	1.4	12.4

775 [1]Carcass conformation score (from S+=18 to P−=1)
776 [2]Random factor variance expressed as % of total variance
777 *P<0.05.
778 **P<0.01.
779 #Restricted feeding
780 çtotal mixed ration
781 [1]Traditional tie-stalls *vs* (Traditional tie-stalls + breeders-fatteners-noTMR + breeders-fatteners-
782 TMR + fatteners-noTMR + fatteners-TMR)
783 [2]Traditional pens *vs* (breeders-fatteners-noTMR + breeders-fatteners-TMR + fatteners-noTMR +
784 fatteners-TMR)
785 [3](breeders-fatteners-noTMR + breeders-fatteners-TMR) *vs* (fatteners-noTMR + fatteners-TMR)
786 [4](breeders-fatteners-noTMR + fatteners-noTMR) *vs* (breeders-fatteners-TMR + fatteners-TMR)

787   [5] (breeders-fatteners-TMR + fatteners-noTMR) *vs* (breeder-fatteners-noTMR + breeders-TMR)

Table 7. Descriptive statistics, ANOVA, and effects of beef production system and carcass weight on meat colour traits.

	L*	a*	b*	C*	h*
General mean	39.8	28.6	9.6	30.2	18.5
Standard deviation	3.5	1.7	1.7	2.1	2.0
ANOVA					
Slaughter batch[1] (%)	19.3	24.2	22.4	23.6	21.1
Farm within system[1] (%)	7.1	3.5	3.3	3.3	3.5
Birth season (*F-value*)	0.3	2.3	1.8	2.4	1.2
Parity of dam (*F-value*)	1.3	2.5	2.5	2.5	1.8
Beef production system (*F-value*)	3.1*	1.8	2.3	2.0	2.1
Carcass weight (*F-value*)	14.8**	31.3**	34.7**	33.6**	30.0**
Beef production system (*LS-means*)					
Traditional systems[#]:					
Tie-stalls	40.8	28.98	10.0	30.67	18.86
Pens	39.6	28.57	9.6	30.15	18.36
Breeder-fatteners, *ad lib*:					
TMR[ç]	39.3	28.72	9.6	30.31	18.37
no TMR[ç]	40.7	28.80	9.9	30.45	17.78
Fatteners, *ad lib*:					
TMR[ç]	39.7	28.41	9.4	29.95	18.19
No TMR[ç]	39.7	28.61	9.6	30.20	18.44
Contrasts (*estimate*):					
Tie-stall *vs* loose-housing[1]	0.9*	0.31	0.3	0.40	0.37
Restricted *vs ad lib*[2]	-0.3	-0.06	-0.1	-0.08	-0.08
Breeders-fatteners *vs* fatteners[3]	0.4	0.25	0.3	0.31	0.26
TMR[ç] *vs* no TMR[ç4]	-0.8*	-0.14	-0.2	-0.19	-0.33
Interaction[5]	0.6	-0.06	0.1	-0.05	0.08
Carcass weight (*LS-means*)					
<350 kg	38.8[a]	27.7[a]	8.6[a]	29.0[a]	17.1[a]
351-400 kg	39.4[a]	28.2[a,b]	9.3[b]	29.7[a,b]	18.1[b]
401-450 kg	39.4[a]	28.5[b]	9.5[b]	30.1[b]	18.4[b]
451-500 kg	40.3[b]	29.1[c]	10.1[c]	30.8[c]	19.0[c]
> 500 kg	41.9[c]	29.9[d]	11.0[d]	31.9[d]	20.0[d]
RMSE	2.9	1.4	1.3	1.7	1.7

[a,b,c,d]=$P<0.05$

[1] Random factor variance expressed as % of total variance.
*$P<0.05$.
**$P<0.01$
[#] Restricted feeding

795   ^çTotal mixed ration

796   [1]Traditional tie-stalls *vs* (Traditional tie-stalls + breeders-fatteners-noTMR + breeders-fatteners-

797   TMR + fatteners-noTMR + fatteners-TMR)

798   [2]Traditional pens *vs* (breeders-fatteners-noTMR + breeders-fatteners-TMR + fatteners-noTMR +

799   fatteners-TMR)

800   [3](breeders-fatteners-noTMR + breeders-fatteners-TMR) *vs* (fatteners-noTMR + fatteners-TMR)

801   [4](breeders-fatteners-noTMR + fatteners-noTMR) *vs* (breeders-fatteners-TMR + fatteners-TMR)

802   [5](breeders-fatteners-TMR + fatteners-noTMR) *vs* (breeder-fatteners-noTMR + breeders-TMR)

803 **Table 8.** Descriptive statistics, ANOVA, and effects of beef production system and carcass weight
804 on meat quality traits.

	pH	Purge losses %	Cooking losses %	Shear force N
General mean	5.56	4.51	16.8	40.97
Standard deviation	0.06	1.20	3.4	10.36
ANOVA				
Slaughter batch[1] (%)	63.1	13.6	43.1	41.8
Farm within system[1] (%)	4.5	7.3	3.1	5.2
Birth season (*F-value*)	0.2	3.9*	0.5	3.4*
Parity of dam (*F-value*)	2.5	2.7*	0.7	0.7
Beef production system (*F-value*)	2.2	0.7	0.9	0.6
Carcass weight: (*F-value*)	3.9*	6.6**	4.5**	0.8
Beef production system (*LS-means*)				
Traditional systems[#]:				
Tie-stalls	5.54	4.24	16.28	39.47
Pens	5.55	4.23	16.54	39.30
Breeder-fatteners, *ad lib*:				
TMR[ç]	5.56	4.24	16.42	40.68
No TMR[ç]	5.55	4.47	16.08	40.21
Fatteners, *ad lib*:				
TMR[ç]	5.55	4.44	16.37	40.00
No TMR[ç]	5.56	4.38	15.85	41.17
Contrasts (*estimate*):				
Tie-stall *vs* loose-housing[1]	-0.010	-0.086	0.058	-0.87
Restricted *vs ad lib*[2]	-0.006	-0.153	0.360	-1.22
Breeders-fattener *vs* fatteners[3]	0.003	-0.059	0.144	-0.14
TMR[ç] *vs* no TMR[ç4]	0.004	-0.086	0.430	-0.35
Interaction[5]	-0.009	0.146	0.089	-0.82
Carcass weight (*LS-means*)				
< 350 kg	5.55[a,b]	3.67[a]	15.2[a]	38.52
351-400 kg	5.55[b]	4.45[b]	16.7[b]	40.81
401-450 kg	5.55[b]	4.38[b]	16.8[b]	40.56
451-500 kg	5.56[a]	4.56[b]	16.5[b]	40.21
> 500 kg	5.55[a,b]	4.62[b]	16.1[a,b]	40.59
RMSE	0.03	1.06	2.5	7.68

805 [a,b,c,d]=$P<0.05$

806

807 [1]Random factor variance expressed as % of total variance.

808   *P<0.05.

809   **P<0.01

810   #Restricted feeding

811   çTotal mixed ration

812   1Traditional tie-stalls *vs* (Traditional tie-stalls + breeders-fatteners-noTMR + breeders-fatteners-

813   TMR + fatteners-noTMR + fatteners-TMR)

814   2Traditional pens *vs* (breeders-fatteners-noTMR + breeders-fatteners-TMR + fatteners-noTMR +

815   fatteners-TMR)

816   3(breeders-fatteners-noTMR + breeders-fatteners-TMR) *vs* (fatteners-noTMR + fatteners-TMR)

817   4(breeders-fatteners-noTMR + fatteners-noTMR) *vs* (breeders-fatteners-TMR + fatteners-TMR)

818   5(breeders-fatteners-TMR + fatteners-noTMR) *vs* (breeder-fatteners-noTMR + breeders-TMR).

819

820   **Highlights**

821   • EU defined fattening systems are characterised using a case study.

822   • Six beef production systems in the fattening of the Piemontese breed can be identified.

823   • Carcass traits of Piemontese young bulls are strongly affected by production system.

824   • Beef production system exerts little effect on meat quality, limited to lightness.