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

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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, *ad libitum* feeding and use of total mixed rations [TMR]), and the different systems now coexist (Sgoifo Rossi, Pastorello, Caprarotta, & Compiani, 2011).

A few studies have looked at the effects of production system or feeding techniques during the fattening period on carcass and meat quality traits (Daza, Rey, Lopez-Carrasco, & Lopez-Bote, 2014; Avilés, Martínez, Domenech, & Peña, 2015). Other studies have also focused on the possible impact of type of animal management before the fattening period on production and meat quality (Dannenberger, Nuernberg, Nuernberg, & Ender, 2006; Guerrero et al., 2013). However, most of the studies investigated very general effects, such as intensive *vs* extensive systems or concentrate *vs* forage feeding.

More recent studies highlighted that individual information on rearing conditions of animals can be exploited with the aim of identifying management techniques affecting carcass and meat quality traits (Gagaoua, Monteils, Couvreur, & Picard, 2017) or to develop predictive models for the same traits (Soulat, Picard, Léger, & Monteils, 2016; Soulat, Picard, Léger, & Monteils, 2018).

Currently no detailed analyses of the fattening systems classified as B&F and specialised fatteners, especially in relation to their effects on animal performance and meat quality traits, and particularly with regard to hypertrophic breeds exist.

The aim of this study, therefore, was to characterise the beef production systems and assess their effects on carcass and meat quality traits using Piemontese breed as a case study.

This knowledge is important for: making a sound economic and technical comparison of the different systems, for predicting future trends in carcass and meat quality trait at population level in the light of the evolution of beef production systems, and for setting future selection goals for genetic improvement of the breed.

2. Material and Methods

This study is part of the "Qualipiem" project, which is aimed at analysing the phenotypic and genetic sources of variation in meat quality traits in the Piemontese breed and at proposing innovative selection strategies for their improvement.

2.1. Farm sampling and data collection

Information on the farms was collected through an interview-based field survey. A total of 115 farms in the Piedmont region (north-west Italy) were selected according to the following criteria: they were interested in the aims of the research, their cows were registered in the Piemontese Herd Book (only for B&F farms), they were using, at least in part, artificial insemination, and were delivering their slaughter animals to the largest local cooperative slaughterhouse. Trained technicians visited each farm selected and assisted the farmer in filling out a questionnaire designed to elicit information on farm size (land area in ha and number of fattened animals per year), management practices and animal welfare. Information about management practices included: beef production system (B&F *vs* specialised fatteners), housing system (tie-stalls *vs* loose-housing), feed supply (restricted *vs ad libitum*), feed distribution (TMR *vs* separate distribution of concentrates and forage) and feed composition (as proportions in rations). In order to obtain chemical composition of feeding, analytical information of purchased commercial feeding was registered, whereas for farm produced feedstuffs, chemical composition of feeds used was derived from the chemical analysis of each feed ingredient (Sauvant et al. 2004). The animal welfare information included space allowance (m^2 per head) and assessments of building adequacy, cleanliness, aeration, water availability and animal docility on a scale of 1 to 3 (1=insufficient, 2=sufficient, 3=good). Farms were also given an overall evaluation by averaging the above-mentioned scores with the exception of animal docility.

The questionnaire was tested before its application for data collection on a sample of farms during the training of technicians.

2.2 Animals and beef sampling

The study was carried out sampling 1,327 Piemontese young bulls progeny of 204 A.I. purebred sires and 1,286 dams, all registered in the Italian Piemontese Herd Book. All the animals were slaughtered at the same commercial abattoir (Operti, Centallo (CN), 12044, Italy) from April 2015 to February 2017. The young bulls were stunned using captive-bolt pistol prior to exsanguination and dressed according to standard commercial practices. Slaughtering was performed in compliance with the Italian welfare regulations and respecting EU regulations (Council Regulation (EC) No. 1099/2009). After slaughter, hot carcass weight (CW) and carcass conformation class according to the EU linear grading system (Commission of the European Communities 1982) were recorded. In order to better differentiate carcass conformation, the six main grades (S, E, U, R, O, P, from best to worst) were further divided into three subclasses (+,= or -) as allowed by European Union regulations (Hickey, Keane, Kenny, Cromie, & Veerkamp, 2007). Prior to statistical analysis, the categories of carcass conformation were rearranged into numerical scores (EUS) ranging from 1, corresponding to class "P-", to 18, corresponding to class "S+". Fatness was not scored in this study as the carcasses of double-muscled breeds are known to be lean and hence exhibit little variation in fatness.

Age at slaughter (AS) was calculated from date of birth to date of slaughter. As individual live weights of animals were not available, daily carcass gain (CDG) calculated as the ratio of carcass weight to age at slaughter, was used as measure of young bulls growth rate (Juniper et al., 2005; Boukha et al., 2011).

The carcasses were not electrically stimulated and they were chilled at 4 °C until twenty-four hours post-mortem. Twenty-four hours after slaughter, individual samples (4.0 cm thick) of the *Longissimus thoracis* (LT) muscle were collected from between the fifth and sixth thoracic vertebrae. The muscle and the excision area were chosen because displayed during the routine slaughterhouse procedures of subdivision of half-carcasses into quarters according to pistol cutting.

The beef samples were scanned with a HP Scanjet 5590 Digital Flatbed Scanner (Hewlett-Packard; Palo Alto, California) to obtain images for subsequent measurement of the rib eye area (REA, cm^2). For image calibration, a ruler marked in centimeters was scanned with meat samples. Then, samples were individually vacuum packed and transferred under refrigerated conditions to the laboratory, where they were stored in a chilling room at 4°C for 7 days, after which meat quality traits were measured.

2.3. Analysis of meat quality traits

After ageing (7 days), purge losses (PL) were determined according to the following procedure: the steaks were first weighed in the bag (packaged weight, W1), then after removal from the bag (unpackaged weight, W3), and then the bag was rinsed, dried and weighed (bag weight, W2). PL (%) was calculated as (W1-W2-W3)/(W1-W2) × 100.

Ultimate pH (7 days) was measured with a portable Crison pH-meter PH 25+ (Crison Instruments S.A.; Alella, Barcelona) equipped with a glass electrode Crison 52 32 suitable for meat penetration and an automatic temperature compensator. Before analysis, the pH-meter was calibrated using standard buffers (pH 4.0 and 7.0). The electrodes were inserted approximately 1 cm into the muscle (Boccard et al. 1981).

The digital images of the samples were processed with the Image Pro Plus 4.5.1. software (Media Cybernetics, 2001) in order to measure the rib eye area (REA, cm^2). Before each measurement, the image was calibrated with a ruler. The surrounding edge of the sample was automatically traced. However, a manual trace by the operator was added when errors in the automatically trace occurred. Only one experienced operator performed all the measurements.

Colour was measured with a Konica Minolta CR-331C colourimeter (Konica Minolta Sensing Americas, Inc; Ramsey, New Jersey) on the freshly-cut surface of each steak after blooming for 1 h at 4°C. The CR-331C colourimeter features 45° circumferential illumination/0° viewing geometry, a Ø25mm measuring area and 2° standard observers. The instrument was calibrated on its own white reference tile supplied by the manufacturer and set with the illuminant D65 (colour temperature 6500 K), which represents average daylight. CIELAB coordinates (CIE 1976), lightness (L*), redness (a*) and yellowness (b*) were recorded, and hue angle (h*) was calculated as $h^* = \tan^{-1}(b^*/a^*)$, Chroma (C*) as $C^* = (a^{*2} + b^{*2})^{0.5}$. Three random readings were taken at different locations on the meat surface and averaged.

After colour measurements had been taken, cooking losses (CL) were determined. Each steak was sealed in a polyethylene bag and cooked in a water bath preheated at 75°C to an internal temperature of 70°C. The cooking temperature was monitored with a thermometer inserted into the geometric centre of the steak. When the set temperature was reached, the steak was removed from the water bath and cooled for 30 min under tap water to prevent further cooking. It was then removed from the bag, blotted and reweighed (Honikel, 1998). Cooking Losses (%) were calculated as the weight difference between the raw and the cooked samples as percentage of the weight of the raw meat sample. The steaks used to determine cooking losses were also used for the Warner Bratzler shear force (WBSF) test after overnight chilling at 4°C. Six cylindrical cores of cooked meat 1.27 cm in diameter, taken parallel to the muscle fibres were sheared perpendicularly to the longitudinal orientation of the muscle fibres with a V shaped Warner-Bratzler cutting blade fitted to an Instron 5543 Universal Testing Machine (Instron; Norwood, Massachusetts). WBSF was measured as the maximum force (Newtons) required to shear the cylindrical core at a crosshead speed of 200 mm per min (A.M.S.A., 2015).

2.4. Statistical analyses

2.4.1. Identification and characterisation of beef production systems

Recent studies (Gagaoua et al., 2017; Soulat et al., 2018) implemented innovative statistical methodologies combining factorial or principal component with cluster analyses for the study of meat quality traits. These methods were able to efficiently categorize animals into management groups and proved to be particularly useful when a very high number of quantitative or qualitative variables were involved. In the present study, the limited number of parameters related to structural and technical features of the investigated farms and the categorical nature of these parameters suggested the authors to perform an agglomerative hierarchical cluster analysis.

The systems were then classified by cluster analysis (Lin & Lin, 1994) on the basis of the following four variables: beef production system (B&F *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).

A dissimilarity matrix was created with the SAS DISTANCE procedure (2013) using the general dissimilarity coefficient of Gower (1971), an appropriate index for handling nominal, ordinal and (a)symmetric binary data. It was then analysed with the SAS CLUSTER procedure (2013) to create agglomerative hierarchical clusters using Ward's minimum variance method (Murtagh & Legendre, 2014). The optimal number of clusters was chosen on the basis of visual inspection, pseudo T-squared (quantification of the difference in the ratio of between-cluster to within-cluster variance by merging clusters), semi-partial R^2 statistics and validate by calculating average silhouette width (Si) criterion (Rousseeuw, 1987; Gagaoua, Picard, Soulat & Monteils, 2018).

Land area, number of fattened animals per year, number of fattened animals per ha, and animal welfare traits (space allowance, building, cleanliness, aeration, water supply, animal docility and overall environmental evaluations) were subjected to a one-way ANOVA with the identified production systems as the source of variation. Orthogonal contrasts based on the effects of production system were used to compare general management strategies across the identified systems (tie-stalls *vs* all loose-housing; within loose-housing: traditional restricted *vs* modern *ad libitum* feeding; within modern systems: B&F *vs* fatteners, TMR *vs* separated diet and their interaction).

2.4.2. Statistical analysis of carcass and meat quality traits

The effects of production system on carcass and meat quality traits were assessed on the basis of individual data from the 1,327 young bulls sampled after removing observations falling outside the range of 3 standard deviations from the mean for each trait. Age at slaughter and carcass traits were analysed with the SAS MIXED procedure (2013) adopting the following statistical model:

$$y = \text{birth season} + \text{parity of dam} + \text{production system} + \text{farm(production system)} + \text{batch} + \varepsilon$$

where y represents the observation of each of the investigated traits; birth season (4 classes: January-March, April-June, July-September, October-December), parity of dam (4 classes: 1st, 2nd, 3rd-8th, >8) and production system are all fixed effects, farm is the random effect of the fattening farm nested within production system (98 levels), batch is the random effect of the day of slaughter (117 levels) and ε is the random residual term. Farms, batch and ε were assumed to be normally and independently distributed $\sim N(0, \sigma^2)$. A minimum cell size of 3 observations was required for both the batch and farm effects.

The fixed effect of carcass weight, (5 classes: <350kg, 350-400kg, 401-450kg, 451-500kg, >500kg) was added to the previous model for the analysis of meat quality traits.

The effects of different management strategies were evaluated with orthogonal contrasts, whereas comparisons of the least square means of the other fixed effects were performed with a Tukey-Kramer test (P<0.05).

3. Results

3.1. Beef production systems

Six clearly recognizable production systems with a good assignment of farms to groups (best silhouette width criterion S_i=0.73) were identified from the cluster analysis (Table 1). Farms characterised by restricted feeding without the use of TMR were classified as traditional systems, with a distinction made between tie-stall and loose-housing of animals. Modern farms, characterised by loose-housed animals fed *ad libitum*, were divided into B&F or specialised fatteners, each further differentiated according to whether not they used TMR.

Traditional farms represented almost 40% of the units surveyed, followed by modern fatteners (33%) and B&F (28%). Nevertheless, almost 41% of the animals sampled came from modern specialised fatteners, 32% from B&F systems and only 27% from traditional farms, reflecting the smaller size of the latter. The distribution of the farms across the criteria used for the cluster analysis allowed us to describe the main characteristics of the beef production systems identified. In half of the farms in the study, cow-calf and fattening operations were integrated, and loose-housing predominated over tie-stalls (77% of farms). The majority of farms (66%) adopted modern a*d libitum* distribution of feed, but only 30% of farms used TMR, probably due to farm size.

Comparison of farm size traits across the identified production systems is shown in Table 2. On average, the farms were 39 ha in size, fattened 82 animals per year with a very large variation across herds, and allocated around 5.00 m^2 of space to each fattening animal. The production system affected ($P < 0.05$) all the traits investigated. Traditional farms with tie-stalls were the smallest ($P < 0.05$), with an average size of 27.4 ha. Within the systems adopting loose-housing, traditional systems with restricted feeding were smaller (32.1 ha) ($P < 0.05$) than modern ones. Farms using TMR were the largest ($P < 0.01$), with an average of 51.5 ha for B&F, 58.7 ha for fatteners. As expected, traditional farms with tied animals allocated the least space ($P < 0.01$) to fattening animals at 2.00 m^2 per head. Average space allowance for loose animals was lower ($P < 0.01$) in specialised fattener systems than in B&F systems, reflecting the former's more intensive management and higher ($P < 0.01$) animal density. As a consequence of purchasing calves from other farms, specialised fatteners produced about three times more slaughter animals per year than B&F, despite their similar size in terms of land area.

Table 3 shows the effects of production system on some of the indices of animal welfare and environmental conditions. Traditional farms with tie-stalls were the worst overall, with lower ($P < 0.05$) scores for all the traits evaluated (not significant only for animal docility). Although the two traditional systems shared certain management features, those with loose-housing were more similar in structural traits to the modern systems. Among the modern systems, overall conditions were better (P < 0.01) in those using TMR, mainly as a consequence of more modern buildings.

Diet compositions in the different production systems are compared in Table 4. Ground corn was the main feed in every system, accounting for between 30 and 40% of the concentrate mix or TMR supplied to fattening animals. Corn silage was very seldom part of the diet in the systems analysed, and even when it was detected (11 of the 115 farms), as in some TMR specialised fattener units, it was never the main component of the diet. Ear corn silage was widely used in TMR systems (P < 0.01) and was an important part of the diet, especially in B&F units. Furthermore, in TMR systems, individual feed ingredients were far more widely used than purchased compound feeds (P < 0.01). In all the other systems, the use of commercial compound feed was common, with average proportions in the diets ranging from 30% (traditional, pens) to 49% (B&F, without TMR). In the traditional and modern systems that didn't use TMR, hay distributed *ad libitum* was always used as forage, while a mixture of hay and wheat straw was included in the feed in both TMR systems.

Table 5 shows the estimated chemical composition of the concentrates supplied in the different beef production systems, expressed as percentage of raw feed. On average, concentrates contained 13% crude protein (CP), 6% crude fibre (CF), 4% ether extract (EE) and 5% ashes (AS). The CP content differed (P < 0.01) across production systems, with the lowest proportions found on farms using TMR, probably due to ear corn silage being a substantial component of the diet.

3.2. Carcass and meat quality traits

Descriptive statistics, the ANOVA results and the effects of beef production system on the carcass traits of Piemontese young bulls are presented in Table 6. The average carcass weight of the Piemontese young bulls sampled was 438.1 (±43.6) kg, while the average age at slaughter was 540.9

(±63.2) days, giving an average daily carcass gain of 0.818 (±0.107) kg/d. Average EUS was 14.66, corresponding to an average evaluation approaching "E+" in the EU linear grading system.

The effect of individual farm within production system explained a proportion of the total variance that varied greatly according to the trait considered, from only about one twentieth in the case of the rib eye area, one tenth for EUS, a quarter for carcass weight and daily carcass gain, to about half for age at slaughter (Table 6), highlighting that the large variability in management techniques still exists even within a given production system. The results show that the batch effect, i.e. animals slaughtered on the same day, explained a much smaller amount of variance than farm, ranging from 4.7% for daily carcass gain to 17.6% for the rib eye area. In the case of the latter trait, it is possible there was an influence of slaughterhouse operator during the sample collection.

Production traits (age at slaughter and daily carcass gain), but not carcass quality (EUS and rib eye area), were affected by the young bulls' birth season ($P < 0.01$) (results were most favourable in the January/March season, the least in the April/June season) and the parity of their dam ($P < 0.01$) (the most favourable results were obtained for 3rd-8th parity class).

Production system affected age at slaughter ($P < 0.05$), carcass daily gain ($P < 0.01$) and SEUROP ($P < 0.05$). The results for the traditional beef system with tied animals, in particular, were much worse than all the systems with loose-housed animals: tied young bulls grew more slowly ($P < 0.01$) (-0.070 kg/d), over a longer ($P < 0.01$) fattening period (+40 d) to reach a similar weight (-10 kg), and their carcasses had lower ($P < 0.01$) muscularity scores (-0.64) and less ($P < 0.05$) rib-eye area (-3.2 cm^2). The production traits of the 5 beef systems rearing loose-housed animals did not differ much, except that the rib-eye of carcasses produced on modern B&F farms had larger ($P < 0.05$) cross-sectional area than those produced by specialised fatteners (+3.2 cm^2).

As shown in Tables 7 and 8, colour and meat quality traits were consistently affected by batch, which explained an average of around 30% of total variance, ranging from 14% for PL to 63% for pH, the latter trait characterised by little overall variability. The amount of variance explained by the effect of farm within beef system, instead, was almost negligible, with L* and PL having the highest values at around 7% of total variance.

Colour traits, pH and CL were not affected by the young bulls' season of birth nor by the parity of their dams, although both of them had a moderate (P < 0.05) influence on PL and the former on shear force (P < 0.05).

The class of carcass weight was a very important source of variation in all meat quality traits, with the only exception of shear force as the LSMs of the heaviest class were always higher (P < 0.05) than those of the lightest.

After taking into account the effects of all the other sources of variation included in the model, beef production system was found to have very little influence on the quality traits. In fact, the differences between the production systems were significant only for one of the colour traits, L*. The traditional tie-stall system produces meat with the highest (P < 0.05) L* value, probably due to the animals' lack of physical activity, underlined by the contrast between tie-stalls and all loose-housing systems. Feeding was also found to influence (P < 0.05) the L* of meat, which was darker from animals fed TMR than from animals fed separated concentrates and hay. We did not find production system to have any influence on pH, shear force and the two water loss traits, PL and CL.

4. Discussion

4.1. Beef production systems

Few previous studies have directed attention to characterising the farming systems used in beef production. Some recent studies are focused on geographical areas and production techniques far from EU conditions (Asem-Hiablie, Rotz, Stout, & Fisher, 2017; Asem-Hiablie, Rotz, Sandlin, Sandlin, & Stout, 2018; Cavalcante et al., 2018). The use of the Piemontese breed as a case study, allowed to analyse in detail the beef production system in an European context. Due to the characteristics of the present research, the obtained results could be of interest also for other European beef breeds characterised by lean carcasses and for European production systems characterised by intensive fattening.

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

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

Boucqué, Fiems, Cottyn, & Buysse (1984) suggested that a CP content exceeding 140 g/kg DM was required for Belgian Blue young bulls. De Campeneere, Fiems, Cottyn, & Boucqué (1999) suggested a CP concentration decreasing from 163 to 120 g CP/kg of dry matter intake (DMI) for the same breed at different stages of life as a function of the animal's body weight. Reducing the CP content in the diet of purebred Piemontese young bulls from 145 g/kg to 108 g/kg of DMI across the whole fattening cycle was not found to affect growth performance (Schiavon, Tagliapietra, Dal Maso, Bailoni, & Bittante, 2010), nor carcass and meat quality traits (Schiavon et al., 2011), but it improved the efficiency of dietary nitrogen use (Schiavon, Tagliapietra, Dalla Montà, Cecchinato, & Bittante, 2012).

The crude fibre content of the concentrate mix was also relatively low (6.0±1.6% as fed), especially when the modest level of corn silage and dry roughage included in the rations compared with other beef systems was considered (Cozzi, Mazzenga, Contiero, & Burato, 2008). In assessing the high energy content of the diets used in all the beef production systems studied here, consideration should be given to the very low fat deposition ability of all double-muscled breeds (Fiems, 2012) and the difficulty in reaching the minimal level of carcass fatness required by the beef market.

4.2. Carcass and meat quality traits

Piemontese cattle are highly specialised for beef production as they are double-muscled, a specific mutation of the myostatin gene (mh) located on Chromosome 2 (Grobet et al., 1998), which is almost fixed in this population. Moreover, this breed is heavily selected for improvement in growth rate and carcass conformation (Albera, Mantovani, Bittante, Groen, & Carnier, 2001) and also, unlike the Belgian Blue, for ease of calving (Kizilkaya et al., 2003). Like other double-muscled breeds, Piemontese cattle have large muscular masses and low fat deposition, and reduced incidence of the skeleton, lower feed intake and better feed conversion (Fiems, 2012) than non-double-muscled specialised beef breeds.

Average values for carcass traits were consistent with those reported in a previous study on the carcass and meat quality traits of Piemontese young bulls (Boukha et al., 2011). In our study, carcass weight was slightly higher, as was the age at slaughter, hence average daily carcass gain was very similar. The average EUS we obtained, close to the “E+” class, is greater than the “E-” average score reported in the aforementioned study (Boukha et al., 2011) and also had slightly lower variability.

There is very little information in the literature on the rib eye area of purebred Piemontese animals. The average value of the rib eye area obtained in the present study was comparable to those reported by Tatum, Gronewald, Seideman, & Lamm (1990) and by Wheeler, Cundiff, Koch, & Crouse (1996) for crossbred Piemontese steers.

The quality of meat from double-muscled Piemontese animals meets the requirements of Italian consumers. It has higher water and protein contents and lower levels of intramuscular fat, usually about 1% (Barge, Brugiapaglia, Destefanis, & Mazzocco, 1993), than meat from conventional animals while the low collagen content is responsible for its greater tenderness (Destefanis, Barge, & Brugiapaglia, 1994). Meat from the Piemontese young bulls and heifers is also in the European Union's register of protected geographical indications (PGI) as “Vitelloni Piemontesi della Coscia” (Reg. no. 703/2017, 5th April 2017).

The results on meat quality in this study also largely agreed with those reported in previous studies on the Piemontese breed (Boukha et al., 2011; Cecchinato, De Marchi, Penasa, Albera, & Bittante, 2011). As in those studies, pH values displayed very small variability and did not exceed 5.87, the value proposed by Page, Wulf, & Schwotzer (2001) as the approximate cut-off between normal and dark-cutting beef carcasses. The average pH value obtained in this study was also very close to those reported by Boukha et al. (2011) for Piemontese young bulls and by Fiems, De Campeneere, Van Caelenbergh, De Boever, & Vanacker (2003) for Belgian Blue bulls.

Meat colour results were very similar to those found by Page et al. (2001) from 1,062 beef carcasses, both in terms of average values and variability, but differed from those reported by Boukha et al. (2011) probably due to the different instruments used for colour detection. We obtained lower average values for CL and shear force compared with Destefanis, Brugiapaglia, Barge, & Lazzaroni's (2003) results for Piemontese young bulls and steers, but we found greater variability in both traits, as expected when comparing a large field survey with an experimental trial.

4.3. Effects of carcass weight on meat quality traits

In general, our results revealed a marked effect of carcass weight on colour and meat quality traits. It should be noted that carcass weight is not to be taken as resulting from prolonging or shortening the fattening period of a given young bull, but is rather a measure of young bulls heavier or lighter carcasses. Carcass weight was related to age at slaughter (r = +0.24), but especially to daily carcass gain (r = +0.56), and probably also to dressing percentage and fat deposition. Indeed, young bulls with higher daily carcass gains were of a lower age at slaughter and reached commercial maturity faster.

The heavier carcasses were associated with brighter meat resulting from a combination of higher values in all the three colour coordinates. The relationship between carcass weight and L* was reported by Murray (1989), who analysed 7,695 beef carcasses produced in field conditions and found that carcass weight was inversely related to the incidence of dark meat: carcasses weighing less than 272 kg had twice the incidence of dark meat (5.1%) than those weighing more than 318 kg (2.6%). Furthermore, in a study on Charolais, Limousin and dairy-cross animals, Craigie et al. (2010) found that a* and b* were associated with carcass weight.

Irrespective of the production system, carcass weight also had a strong effect on most of the other quality traits. We found a significant effect of carcass weight class on pH, but we do not expect any practical implications as the variability in this trait was very small. The water holding capacity of meat tends to be higher in the lighter carcasses. The trend for PL to increase with carcass weight at slaughter may be related to the slower cooling rates in heavier carcasses. Relationships between carcass weight or live weight and tenderness have sometimes been found in experimental studies on the effects of prolonging the duration of fattening. In a study on Charolais heifers, Ellies-Oury et al. (2017) reported a significant effect of slaughter weight on meat tenderness only with older animals, the lower values associated with greater carcass weight, whereas no effect was found with younger animals. Similar results were obtained by Sañudo et al. (2004), who reported that the meat of young bulls slaughtered at 550 kg live weight was more tender than that of young bulls slaughtered at 300 kg. In our study, 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 experiment rather than answering a need to comply with market requirements. Conversely, a recent study by Soulat et al. (2018) focused on the possibility to predict carcass quality of beef crossbred heifers showing the importance of whole life rearing factors over carcass traits.

4.5. Effects of beef production systems on meat quality traits

In this study, the batch effect explained a large proportion of total variance in meat quality traits, with the exception of pH. As this effect regards animals slaughtered on the same day, it encapsulates the effects of pre-slaughter and slaughter conditions (Adzitey, 2011) and post-mortem handling of carcasses (Warris, 2000). It also includes possible effects of calibration of the equipment used for the physical analyses and of laboratory operators, which are important sources of variation in several meat quality traits. In general, the effects of beef production system and of individual farm within production system on meat quality traits were of a small magnitude. These findings agree with the principles adopted by Meat Standards Australia (MSA) system (Bonny et al., 2018), which puts more focus on slaughter conditions, carcass characteristics, ageing time and cooking techniques than on rearing factors to deliver an eating quality guarantee to consumers.

In our study the effect of production systems was appreciable only for L*, reflecting the possible influence of stall and feeding system on meat colour. Our results agree with Brugiapaglia & Destefanis (2012), who found that the meat of tie-stalled Piemontese young bulls had higher L* and b* values than those of animals fattened in pens. Indeed, the darker meat of animals reared in loose conditions could be related with the muscle's greater oxidative capacity resulting from physical activity (Vestergaard, Oksbjerg, & Henckel, 2000; Jurie, Ortigues-Marty, Picard, Micol & Hocquette, 2006). The anatomical position of the muscle and its involvement in movement also play an important role in colour variation (Dunne, O'Mara, Monahan, French, & Moloney, 2005).

Regarding feeding system, our study revealed that meat from animals on a TMR diet was associated with lower L* values, resulting in a slightly darker colour, in agreement with the findings of Avilés et al. (2015), who reported that meat from calves fed traditionally was paler than meat from TMR-fed calves, although feeding system did not have a significant effect on the other colour traits. Jurie et al. (2006) highlighted a combined effect of pasture and grass diet *vs.* maize silage-based diet on meat colour, while other studies found no clear relationships between feeding system and meat colour (French et al., 2001; Daza et al., 2014).

Apart from colour traits, the scientific literature provides no clear evidence of a relationship between farm management and meat quality. Even when comparison have been made between management systems with greater differences than those examined in this study, such as intensive *vs* extensive fattening, results have often been inconsistent or conflicting. This tendency was also observed in our study where no influence of production system on pH, shear force, PL and CL could be detected. Consistent with our findings, studies by Daza et al. (2014), Cerdeño, Vieira, Serrano, Lavín, & Mantecón (2006) and French et al. (2001) found no effect of feeding system on PL. Guerrero et al. (2013) reported an effect of pre-finishing management of young bulls on PL but not on CL. More recently, Gagaoua et al. (2018) highlighted an effect of carcass fatness over young bulls' meat tenderness, juiciness and flavour. Moreover, they also reported that animals with shorter fattening duration and lower body weight at the beginning of the fattening period were able to produce meat with better eating quality. Soulat et al. (2018) showed that the prediction of meat quality traits obtained from rearing factors were less accurate than those of carcass traits. Nevertheless age at slaughter, ease of birth and genetic potential in muscular development could explain the eating quality of heifers' meat appraised by a tasting panel.

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

As already mentioned in this study, the main change to the beef production systems in the case study area has been the gradual replacement of the traditional system of tied animals with systems using loose-housing. The results obtained here confirm that, aside from improvement in animal welfare and production ethics which are key issues for the European consumers (Hocquette et al., 2018), this trend would greatly improve the animal's production efficiency (daily carcass gain and conformation) without having any undesired effect on meat quality, with the only exception of meat lightness. This goes in the direction of a broader concept relative to a sustainable efficient livestock production, as highlighted by Scollan et al. (2011) and by Hocquette et al. (2018) analysing the future research priorities for animal production. Among the 5 beef systems using loose-housing, there were many differences in terms of number of the manageable animals, capital investments, labour requirements, feeds and welfare issues, with modern systems using TMR fed *ad libitum* being the more efficient. However, the carcass and meat quality traits did not differ much between systems, so no major changes in these traits should be expected in the future as a consequence of changes in farming systems.

Within beef production systems, however, there was large variability among individual farms in carcass weight and daily carcass gain, and particularly for age at slaughter, but not for EUS. A great variability among farms was highlighted also in other studies regarding economic and environmental performances (Veysset, Lherm, & Bébin, 2010; Veysset, Lherm, & Bébin, 2011). This variability should be studied in greater detail to understand which factors, not considered in the present study, may be affecting carcass traits and how they could be exploited to improve production efficiency.

The small effect of beef production system and of individual farm within beef system makes it clear that the variability in carcass conformation and meat quality traits depends mainly on individual animal factors and that improvements to them can be made by taking action at the level of individual animals. As the most important individual factor explaining meat quality was carcass weight class, it is important to understand the extent to which this effect depends on growth rate potential, fat deposition rate, length of fattening period and carcass yield. As only genetics can yield durable improvements in carcass and meat quality, further knowledge of the genetic mechanisms underlying the variations in these traits also needs to be acquired.

5. Conclusions

This study provides a detailed description of beef production systems using as a case study the Piemontese breed, which exemplifies the main beef production systems classified by the European Union. Six main types, according to specific management strategies were identified. Traditional systems coexist alongside more advanced systems using modern technologies. Within the production systems identified, there is still a considerable variation among farms. Carcass traits are strongly affected by production system, with traditional management conditions having lower production efficiency. However, production system exerts only a very small effect on meat quality, limited to colour traits. It appears that meat quality may be conditioned by other factors related to individual animals within farms, suggesting that future improvement should look, in particular, to genetics.

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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.

Table 2. Descriptive statistics and effect of beef production system on farm size, yearly production and 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

[a]Restricted feeding
[b]Total mixed ration
*$P<0.05$.
**$P<0.01$.
[1]Traditional tie-stalls *vs* (Traditional tie-stalls + breeders-fatteners-noTMR + breeders-fatteners-TMR + fatteners-noTMR + fatteners-TMR)
[2]Traditional pens *vs* (breeders-fatteners-noTMR + breeders-fatteners-TMR + fatteners-noTMR + fatteners-TMR)
[3](breeders-fatteners-noTMR + breeders-fatteners-TMR) *vs* (fatteners-noTMR + fatteners-TMR)
[4](breeders-fatteners-noTMR + fatteners-noTMR) *vs* (breeders-fatteners-TMR + fatteners-TMR)
[5](breeders-fatteners-TMR + fatteners-noTMR) *vs* (breeder-fatteners-noTMR + breeders-TMR)

Table 3. Descriptive statistics and effect of beef production system on subjective evaluation of animal 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

[a]Restricted feeding
[b]Total mixed ration
*$P<0.05$.
**$P<0.01$
[1]Traditional tie-stalls *vs* (Traditional tie-stalls + breeders-fatteners-noTMR + breeders-fatteners-TMR + fatteners-noTMR + fatteners-TMR)
[2]Traditional pens *vs* (breeders-fatteners-noTMR + breeders-fatteners-TMR + fatteners-noTMR + fatteners-TMR)
[3](breeders-fatteners-noTMR + breeders-fatteners-TMR) *vs* (fatteners-noTMR + fatteners-TMR)
[4](breeders-fatteners-noTMR + fatteners-noTMR) *vs* (breeders-fatteners-TMR + fatteners-TMR)
[5](breeders-fatteners-TMR + fatteners-noTMR) *vs* (breeder-fatteners-noTMR + breeders-TMR)

Table 4. Effect of beef production system on ingredient composition (% as fed) of concentrate mix and 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	-

[a]Restricted feeding

[b]Total mixed ration

[1]Included other cereal byproducts and distillers and soybean hulls

[2]% of total intake (on average 87.1% meadow hay and 12.9% barley or wheat straw)

[3]% of total intake (on average 86.2% meadow hay and 13.8% barley or wheat straw)

*P<0.05.

**P<0.01

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

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

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

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

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

Table 5. Descriptive statistics and effect of beef production system on nutrient composition of mix 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

[a]Restricted feeding
[b]Total mixed ration
*P<0.05.
**P<0.01.
[1]Traditional tie-stalls *vs* (Traditional tie-stalls + breeders-fatteners-noTMR + breeders-fatteners-TMR + fatteners-noTMR + fatteners-TMR)
[2]Traditional pens *vs* (breeders-fatteners-noTMR + breeders-fatteners-TMR + fatteners-noTMR + fatteners-TMR)
[3](breeders-fatteners-noTMR + breeders-fatteners-TMR) *vs* (fatteners-noTMR + fatteners-TMR)
[4](breeders-fatteners-noTMR + fatteners-noTMR) *vs* (breeders-fatteners-TMR + fatteners-TMR)
[5](breeders-fatteners-TMR + fatteners-noTMR) *vs* (breeder-fatteners-noTMR + breeders-TMR)

Table 6. Descriptive statistics, ANOVA, and effects of beef production system on age of 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[ς]	559	438	0.797	14.92	94.6
No TMR[ς]	515	432	0.849	14.62	92.8
Fatteners, *ad lib*:					
TMR[ς]	549	430	0.789	14.46	89.0
No TMR[ς]	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[ς] *vs* no TMR[ς4]	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

[1]Carcass conformation score (from S+=18 to P−=1)
[2]Random factor variance expressed as % of total variance
[*]P<0.05.
[**]P<0.01.
[#]Restricted feeding
[ς]total mixed ration
[1]Traditional tie-stalls *vs* (Traditional tie-stalls + breeders-fatteners-noTMR + breeders-fatteners-TMR + fatteners-noTMR + fatteners-TMR)
[2]Traditional pens *vs* (breeders-fatteners-noTMR + breeders-fatteners-TMR + fatteners-noTMR + fatteners-TMR)
[3](breeders-fatteners-noTMR + breeders-fatteners-TMR) *vs* (fatteners-noTMR + fatteners-TMR)
[4](breeders-fatteners-noTMR + fatteners-noTMR) *vs* (breeders-fatteners-TMR + fatteners-TMR)

[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[ς]	39.3	28.72	9.6	30.31	18.37
no TMR[ς]	40.7	28.80	9.9	30.45	17.78
Fatteners, *ad lib*:					
TMR[ς]	39.7	28.41	9.4	29.95	18.19
No TMR[ς]	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-fattener *vs* fatteners[3]	0.4	0.25	0.3	0.31	0.26
TMR[ς] *vs* no TMR[ς4]	-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

[ς]Total mixed ration

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

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

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

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

[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.

[*]P<0.05.
[**]P<0.01
[#]Restricted feeding
[ç]Total mixed ration
[1]Traditional tie-stalls *vs* (Traditional tie-stalls + breeders-fatteners-noTMR + breeders-fatteners-TMR + fatteners-noTMR + fatteners-TMR)
[2]Traditional pens *vs* (breeders-fatteners-noTMR + breeders-fatteners-TMR + fatteners-noTMR + fatteners-TMR)
[3](breeders-fatteners-noTMR + breeders-fatteners-TMR) *vs* (fatteners-noTMR + fatteners-TMR)
[4](breeders-fatteners-noTMR + fatteners-noTMR) *vs* (breeders-fatteners-TMR + fatteners-TMR)
[5](breeders-fatteners-TMR + fatteners-noTMR) *vs* (breeder-fatteners-noTMR + breeders-TMR).

Highlights

- EU defined fattening systems are characterised using a case study.
- Six beef production systems in the fattening of the Piemontese breed can be identified.
- Carcass traits of Piemontese young bulls are strongly affected by production system.
- Beef production system exerts little effect on meat quality, limited to lightness.