Replacement of soya bean meal and corn by field peas in young bulls fattening diets: performance, rumen fermentation, nitrogen use and metabolism

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Abstract

This study explored the interest in field peas partially replacing soya bean meal and corn in beef fattening diets by assessing impacts on animal performance, ruminal fermentation, nitrogen (N) use and economic output. Thirty-two Parda de Montaña young bulls (210±24.3 kg BW) were randomly assigned to one of four treatments (0%, 15%, 30%, 45% pea in isonitrogenous and isoenergetic concentrates. After 23 d adaptation, fattening was divided into Growing (first 134 d) and Finishing (from d 135 to 500 kg target slaughter BW). Gains were higher (P<0.001) and the DM intake and feed conversion ratio were lower (P<0.001) during Growing vs. Finishing. The proportion of field peas influenced DM intake (P<0.05) but did not affect days on feed, daily gains, the feed conversion ratio or carcass traits. Ruminal NH_3-N concentrations were lower and total volatile fatty acids (VFA) were higher during Growing vs. Finishing (P<0.001). Ruminal fluid pH was higher and NH_3-N concentration, total VFA and propionic acid were lower in treatment 0% pea (P<0.01), likely because of lower dietary protein and starch degradability. The intake of N did not differ among diets. Faecal N excretion was the lowest and urinary N excretion the highest in treatment 30% pea (P<0.05) during both periods, which was associated with higher ruminal NH_3-N and plasmatic urea concentrations. The economic performance of treatment 30%

pea was the best in four scenarios considering different relative feed ingredient prices. These results support the economic interest in including up to 30% field peas in beef fattening diets but, given the different N partition patterns towards faeces and urine, these alternatives' environmental interest should be assessed at a territorial scale.

Keywords: *Pisum sativum,* beef bulls, high-concentrate diets, ruminal parameters, N partition, economic analysis

Abbreviations

AIA, acid insoluble ash; ADFom, acid detergent fiber exclusive of residual ash; ADG, average daily gain; BHB, β-hydroxy-butyrate; BW, body weight; C_2:C_3, acetic:propionic acid ratio; CV, coefficient of variation; CP, crude protein; DM, dry matter; DMI, dry matter intake; FCR, feed conversion ratio; IGF-I, insulin-like growth factor-1; Lignin sa, lignin determined by solubilization of cellulose with sulfuric acid; N, nitrogen; NEFA, nonesterified fatty acids; NDFom, neutral detergent fiber exclusive of residual ash; NH_3-N, ammonia; OM, organic matter; VFA, volatile fatty acids.

INTRODUCTION

Beef cattle production currently faces numerous challenges that jeopardise its social, economic and environmental viability. In Southern Europe, it is often based on mixed systems with extensive management of adult herds on pastures and intensive fattening of their weaned offspring in landless, indoor systems (Tinitana-Bayas et al., 2024), where dependence on purchased feeds is a major driver of its sustainability (Muñoz-Ulecia et al., 2023). Soya bean is a major protein ingredient in the concentrates used in the fattening phase, but its use raises increasing concerns due to heavy dependence on imports from countries where it has a large impact on deforestation and biodiversity (Rauw et al., 2023).

The European Parliament recently promoted the use of European-grown protein crops as a way to boost protein autonomy, of which leguminous crops also help to address climate and environmental challenges in line with Green Deal objectives (Parliament, 2023). The many ecosystem services provided by legumes and pulses are relevant for not heavily relying on synthetic fertilisers, and for their reduced greenhouse gas emissions, increased above- and below-ground biodiversity, and improved soil fertility and C storage (Watson et al., 2017). For these reasons, legume-based cropping systems have been promoted as a sustainable alternative to fertiliser-based systems for mitigating greenhouse gas emissions in Mediterranean agro-ecosystems (Oliveira et al., 2021). Furthermore, their inclusion as a locally sourced protein in livestock diets can efficiently contribute to reinforce circular economy practices at the territory level given that, despite their lower methionine content in relation to soya bean, lactating and growing ruminants' performance is comparable with both ingredients (Halmemies-Beauchet-Filleau et al., 2018). In fact given their high protein and starch contents, they can substitute not only soya bean, but also cereal grains in diets, although the inclusion rate could be limited by the high ruminal degradability of their protein (Khorasani et al., 2001; Rotger et al., 2006; Keller et al., 2022). Greater protein degradation by rumen microbes results in higher ammonia (NH_3-N) production and can promote a shift in the nitrogen (N) excretion partition from faeces to urine, where N is more prone to leaching and volatile loss (Dijkstra et al., 2013). Nonetheless, very few studies compare N partitioning between urine and faeces when soya bean meal is substituted for raw proteaginous seeds (Mendowski et al., 2021). Conversely, their lower starch ruminal degradability compared to cereal starch (Larsen et al., 2009) reduces the ruminal acidosis risk (Watson et al., 2017), which is particularly interesting in intensive fattening diets.

Among pulses, the use of field peas to substitute soya bean and cereals in forage-based isoproteic diets had no effect on dairy cows' performance (Khorasani et al., 2001; Vander Pol et al., 2008; Pereira et al., 2017). With growing cattle, previous research has primarily focused on the impact of dietary protein content or intake on performance rather than on the effects of different protein sources in isonitrogenous diets (Huuskonen et al., 2014). When field peas were included up to 50% in the forage-based diets of beef steers, the performance and gain to feed ratios were similar to those observed with soya bean supplementation (Reed et al., 2004b; Gilbery et al., 2007; Soto-Navarro et al., 2012). Nevertheless, no studies are available about intact males fed high-concentrate diets, where economic interest depends on their relative price to competing ingredients. Moreover, due to potential trade-offs, environmental aspects like land use or methane and nitrous oxide emissions from enteric fermentation and manure decomposition should also be taken into account for optimal diet formulation for beef cattle (Marques et al., 2022). In this context, the objective of the study was to determine the impact of different rates at which field peas are included to replace soya bean and cereals in the concentrates fed to young beef bulls in animal performance, ruminal fermentation, N use and economic output terms. We hypothesised that, with isonitrogenous and isoenergetic diets, increasing dietary field peas inclusion would not affect their gains or N use efficiency, and this could be interesting from the economic viewpoint because soya bean meal prices are relatively high.

MATERIALS AND METHODS

The experiment was conducted at La Garcipollera Research Station located in the Southern Pyrenees (Spain, 42º 37' N, 0º 30' O, 945 m a.s.l.) in 2017. Experimental procedures were conducted according to the guidelines of European Union Directive 2010/63 on the protection and well-being of animals used for experimental and other scientific purposes, and were approved by the Animal Ethics Committee of the research centre (protocol no. CEEA-03-2014-26).

Animals and management

Thirty-two Parda de Montaña weaned beef calves (210±24.3 kg BW and 152±17.6 days of age) were used in the experiment. Animals were randomly assigned to four groups balanced for BW and age to assess the four treatments, which differed in terms of received concentrate type. During the fattening period, diets consisted of barley straw and one of four pelleted concentrates, which included different proportions of pea to substitute soya bean meal and corn (0% pea, 15% pea, 30% pea and 45% pea). Concentrates were formulated to be iso-energetic (11.7 MJ metabolisable energy (ME)/kg fresh matter (FM)) and iso-proteic (130 g crude protein (CP)/kg FM). The ingredients and chemical composition of concentrates are detailed in Table 1. Of the eight young bulls per treatment, four were randomly allocated to one of two straw-bedded pens and the remaining four to the other pen. Pens were equipped with ALPRO feeding stations (ALPRO Herd Management 7.0, DeLaval) for automatic concentrate distribution on an individual basis, with troughs to provide straw on a pen basis. The experiment started after 23 days of adaptation to pens, diets and feeding system, when bulls received increasing amounts of concentrate in troughs to adapt to diets, and afterwards they were trained to use feeding stations. After adaptation, the study included the whole fattening phase, where the first 134 d were considered the growing period (Growing), and the rest (until bulls reached the target slaughter weight of 500 kg BW) was considered the finishing period (Finishing). Throughout the experiment, bulls had *ad libitum* access to concentrates and straw, water and mineral blocks. At the end of the fattening phase, animals were transported (82 km) to an EU-licenced abattoir and were slaughtered according to commercial practices.

Measurements

Individual concentrate intake was recorded daily throughout the experiment. Straw intake was calculated by assuming that it represented 8% and 13.5% of the total dry matter intake (DMI) during Growing and Finishing, respectively (Costa-Roura et al., 2020). Bulls were weighed weekly at 08:00h without being deprived of feed and water. These measurements were used to calculate the average daily gain (ADG) by the linear regression of BW on date, as well as the feed conversion ratio (FCR). Each month, concentrates samples were collected to determine chemical composition.

The characteristics of ruminal fermentation and the N balance of young bulls were studied twice during the experimental period: at the beginning of Growing (day 8) and 4 months later at the start of Finishing (day 134). Ruminal fluid samples were collected using an oral stomach tube connected to a vacuum pump at the start of Growing (day 8) and Finishing (day 134) to determine pH, NH_3-N and VFA. Each sample was obtained during two sequential collections: firstly, ruminal fluid (approx. 200 mL) was collected and discarded to avoid sample contamination by saliva that may have entered tubes while being introduced through animals' mouth and oesophagus. Afterwards, ruminal fluid (approx. 200 mL) was collected again, strained through four cheesecloth layers and its pH recorded (Testo 205, Testo AG, Germany). Then ruminal fluid was sampled for NH_3-N (2 mL over 0.8 mL of 0.5 N HCl) and VFA concentration (4 mL over 1 mL solution of 0.4 M ortho-phosphoric acid and 0.02 M 4-methylvaleric acid as an internal standard, in distilled water). Samples were immediately frozen with dry ice and stored at -20^{o}C until analyses. On the same day, urine and faeces samples were obtained from each animal to study N balance. Spot urine samples (10 mL) were taken by prepuce stimulation. Then they were strained to remove hair and debris, immediately frozen on dry ice and stored at -80^{o}C until the N and creatinine analyses. Faecal samples (50 g) were collected using rectal stimulation and stored at -20ºC until the N and internal marker (acid insoluble ash, AIA) determinations.

Animals were bled monthly at 08:00 h by venipuncture (with an 18-gauge needle, 2.5 cm long) of the coccygeal vein using test tubes with heparine to determine insulin-like growth factor-1 (IGF-I) concentrations, and test tubes with EDTA to determine non-esterified fatty acids (NEFA), urea, β-hydroxy-butyrate (BHB) and glucose. Plasma was obtained after centrifugation and stored in aliquots before being frozen at –20ºC.

Slaughtering procedures and carcass measurements

Cattle were slaughtered immediately upon arrival to minimise preslaughter stress, stunned by captive bolt pistol, and dressed according to standard commercial practices. Hot carcass weight was recorded immediately after slaughter and carcasses were chilled for 24 h at 4ºC. Then the degree of fat cover of left half carcasses and their conformation were graded according to the European grading system (E.U., 2006). Carcass conformation was based on visual assessment (SEUROP classification) using an 18-point scale (from 1 = poorest to 18 = best). Degree of fat cover was evaluated on a 15-point scale (from 1 = very low to 15 = very high).

Chemical analyses

The chemical compositions of concentrates and the N contents in urine and faeces were determined in duplicate following AOAC methods (2000) for DM (index no. 934.01), ash (index no. 942.05), N (index no. 968.06) and starch (index no. 996.11). Fibres were analysed following the sequential procedure of Mertens (2002) with an Ankom 200/220 fibre analyser (Ankom Technology Corporation, Fairport, NY, USA). NDFom was assayed with heat stable amylase, while lignin was analysed in ADFom residues by cellulose solubilisation with sulphuric acid (lignin (sa)). All the values were corrected for ash-free content. N content was determined using a nitrogen analyser (Model NA 2100, CE Instruments, Thermoquest SA, Barcelona, Spain). The ether extract (EE) was determined following the Ankom Procedure (AOCS, 2005) with an XT10

Ankom extractor (Ankom Technology Corporation). Total starch was determined by a total starch assay kit (Megazyme, USA) (Mccleary et al., 1997). The NH_3-N content in ruminal fluid was assessed by the Berthelot reaction (Chaney and Marbach, 1962) in an Epoch Microplate Spectrophotometer (BioTek Instruments, Inc., Winooski, VT, USA). VFA concentrations (acetic, propionic, iso-butyric, butyric, iso-valeric and valeric acids) were determined using a Bruker Scion 460 GC (Bruker, USA) equipped with a CP-8400 autosampler, FID and a BR-SWax capillary column (30 m × 0.25 mm i.d. × 0.25 µm film thickness, Bruker, USA) using helium as the carrier gas at the 1 mL/min flow rate. The oven temperature programme was 100^{o}C, followed by a 6°C/min increase to 160°C. The injection volume was 1 µl at a split ratio of 1:50. The VFA were identified based on retention time comparisons with commercially available standards of acetic, propionic, iso-butyric, butyric, iso-valeric, valeric and 4-methyl-valeric acids of ≥ 99% purity (Sigma-Aldrich).

Faecal excretion was estimated based on feed intake using AIA as an internal marker. The AIA content in feed and faeces was analysed according to a standard procedure (BOE, 1995) based on the method of Shrivastava and Talapatra (1962). Briefly, residues of ash content determinations were hydrolysed with 75 mL of 3 N HCl and boiled for 15 min. Samples were then filtered through ash-free filter paper (cat no. 1004 150, Whatman) and then residues were washed with 50 mL of hot distilled water. The filters with residues were dried (103^{o}C, 2 h) and then ashed (550^{o}C, 3 h) in a tared crucible. Both the crucible and its content were left in a desiccator to settle at room temperature and were weighed to calculate AIA content. Finally, faecal excretion was calculated using both concentrate and straw intakes and AIA content in feed and faeces as follows:

$$\frac{[\text{AIA}]_{\text{concentrate}} \times \text{concentrate intake} + [\text{AIA}]_{\text{straw}} \times \text{straw intake}}{[\text{AIA}]_{\text{faeces}}}$$

Urine excretion was estimated by assuming a creatinine constant urinary output of 883 µmol per kg metabolic weight and day (Chen et al., 2010). The creatinine concentration in urine was determined by ultrahigh liquid chromatography coupled with mass spectrometry using the adaptation of (Boudra et al., 2012) described in Costa-Roura et al. (2020). N retention was calculated by the difference of N consumed and total N excreted (faecal and urinary).

The blood analysis of concentrations of total protein, BHB (enzymatic colorimetric method) and urea (kinetic UV test) in plasma were determined with an automatic analyser (GernonStar, RAL/TRANSASIA, Dabhel, India). The protocols and reagents for the total protein and urea analyses were provided by the analyser's manufacturer (RAL, Barcelona, Spain). The reagents for BHB were supplied by Randox Laboratories Ltd. (Crumlin, Co. Antrim, UK). NEFA (enzymatic method, sensitivity: 0.06 mmol/L) were analysed using a commercial kit (Randox Laboratories Ltd., Crumlin, Co. Antrim, UK). The mean intra- and interassay coefficients of variation (CVs) for these metabolites were < 4.4% and < 5.8%, respectively. IGF-I concentrations were determined by a chemiluminescent assay system (IMMULITE 1000, Siemens Healthineers, Erlangen, Germany), and the intra- and interassay CVs were 3.6% and 6.6% for the IGF-I analyses, respectively

Economic analysis

The feeding strategies based on the four different concentrates were economically compared using a partial budget analysis, which considered only the technical and economic aspects that varied among strategies and impacted costs and incomes. These were: daily DMI and feed cost; days at feedlot and yardage costs; carcass weight, conformation score and selling price of a young bull at slaughter. The economic margin was calculated as the difference between income and the above-described costs. Cost of inputs (feed and yardage) and carcass selling prices, adjusted according to weight and the conformation score, were those prevailing at the time of the experiment (2017).

To take into account volatility of prices on agricultural markets (FAO, 2011), a sensitivity analysis was performed on concentrate cost (based on the original scenario costs of all the ingredients) in response to the four scenarios with different relative costs of soya bean meal and field peas from 1990 to 2024, obtained from official DACC databases (2024). The scenarios considered the following: Scenario 1, the original costs at the time of the experiment (0.385 €/kg soya bean meal, 0.240 €/kg field pea, 2017); Scenario 2, the maximum soya bean meal cost (0.548 €/kg soya bean meal, 0.399 €/kg field pea, 2022); Scenarios 3 and 4, the maximum and minimum soya bean meal/field peas cost ratio (1.99 and 0.76 in 2021 and 1991, respectively).

Statistical analyses

The data of one young bull from the 30% pea treatment had to be discarded due to health problems unrelated to the experiment.

Statistical analyses were performed with SAS v. 9.1. (SAS Inst. Inc., Cary, NC, USA) and R (R Development Core Team, 2021). Mixed models based on Kenward-Roger's adjusted degrees of freedom solution for repeated measures were used to analyse DMI, BW, ADG, the FCR, ruminal fermentation characteristics (pH, NH_3-N and VFA), N balance and the plasma concentrations of IGF-1 and metabolites. The inclusion of field peas (0%, 15%, 30% and 45%), period (Growing and Finishing), and their interaction, were the fixed effects, and animal was the random effect for DMI, BW, ADG, the FCR, ruminal fermentation characteristics (pH, NH_3-N and VFA) and N balance. The inclusion of pea, sampling date, and their interaction, were taken as the fixed effects and animal as the random effect for IGF-1 and metabolite concentrations in plasma. In all the models, a first-order autoregressive structure with heterogeneous variances for each date/period was employed to model the heterogeneous residual error. Fattening period duration (days on feed to reach the target slaughter BW), slaughter BW, carcass characteristics and economic outcome were analysed by an analysis of variance (ANOVA) by the GLM procedure with the inclusion of pea as the fixed effect. Least square means (LS Means) were estimated and differences between LS Means were tested using pdiff with Tukey correction. For all the tests, level of significance was set at 0.05. Trends were discussed when P-values were < 0.10.

Associations between performance parameters and plasma metabolites were studied by Pearson's rank correlations (r) using the CORRPLOT procedure of R.

RESULTS

Whenever applicable, the results are presented separately for the period and proportion of field peas in the concentrate because the interaction was never significant.

Animal performance

No interaction was observed between the period and proportion of pea included in the concentrate (P > 0.05). Bulls' performance in the four treatments in the fattening phase is presented in Table 2. Period affected absolute DMI (P = 0.01), DMI expressed per metabolic weight ($BW^{0.75}$), daily gains and the FCR (P < 0.001). During Growing, animals presented lower absolute daily DMI (P < 0.001), but higher DMI per kg metabolic weight than during Finishing (P < 0.001). Gains were higher (P < 0.001) and the FCR lower (P < 0.001) during Growing than Finishing.

The proportion of field peas included in concentrates did not affect either young bulls' ADG or the FCR (P > 0.05), but affected the daily concentrate DMI (P < 0.05), which was 10% higher in the bulls fed the 30% pea than in those fed the 45% pea concentrate (P = 0.005). Albeit not statistically different, the young bulls that received the 30% pea concentrate had 9% to 13% greater weight gains (Table 2). Consequently, days on feed needed to attain the target slaughter weight lowered from 12 to 21 days, but not significantly (Table 3). The proportion of peas in concentrates did not affect the slaughter BW and carcass characteristics, with similar carcass weight, and conformation and fatness scores (P > 0.05; Table 3).

Ruminal fermentation parameters

The period affected all the parameters related to ruminal fermentation (Table 4, P ≤ 0.002), except for pH and the proportion of iso-valeric acid (P > 0.05). During Growing, young bulls had lower NH_3-N, acetic, butyric and iso-butyric acids and higher total VFA, propionic and valeric acids than during Finishing

Ruminal fluid pH, NH_3-N concentration and total VFA were affected by the proportion of field peas in concentrates ($P < 0.01$, Table 4), with no significant effect of the interaction with period in any case. pH was higher in the fluid of the young bulls fed the 0% pea concentrate than in that of their counterparts fed the 30% pea and 45% pea concentrates ($P = 0.006$). NH_3-N concentration was lower in the ruminal fluid of the bulls fed the 0% pea and 15% pea concentrates than in those fed the 45% pea concentrate ($P = 0.005$). Total VFA production was lower in the bulls fed the 0% pea than in their counterparts ($P < 0.01$). Inclusion of field peas affected the proportions of propionic, butyric and iso-butyric acids ($P < 0.05$), but not those of acetic or valeric acids ($P > 0.26$). The 30% pea concentrate yielded a higher proportion of propionic acid and less butyric acid than the 0% pea concentrate ($P < 0.05$), with intermediate values for the other concentrates ($P > 0.05$). The 0% pea concentrate yielded a higher proportion of iso-butyric acid than the other concentrates ($P = 0.01$). Inclusion of field peas tended to affect the proportion of iso-valeric ($P = 0.06$) and the C_2:C_3 ratio ($P = 0.07$), with a trend towards a higher proportion of iso-valeric acid and a higher C_2:C_3 ratio in the rumen of the bulls fed the 0% pea concentrate.

Nitrogen balance

Period affected N intake, N excretion in the faeces and urine and retained N ($P < 0.02$), with lower values for Growing than for Finishing ($P < 0.001$; Table 5). The proportion of field peas in concentrates did not influence either N intake or absolute retained N, but affected N excretion in faeces ($P = 0.01$) and urine ($P = 0.04$). 0% pea showed more N excretion in faeces than the 30% and 45% pea concentrates, and lower N excretion in urine than for 30% pea.

Plasma IGF-I and metabolites

The IGF-I concentration in plasma was affected only by sampling date (P < 0.001; Figure 1) with a rise in concentration on the 60 first days. The concentrations of total protein, NEFA and BHB in plasma were affected only by sampling date. Total protein peaked at day 60 and remained high until day 150. NEFA peaked at days 120-150, and BHB contents plateaued from day 30 to day 150 (P < 0.001; Figure 2). Urea concentration was affected by both studied factors, that is, sampling date and proportion of pea (P < 0.001; Figure 2), with lower values at the start of Growing and in the young bulls on the 0% pea concentrate than in their counterparts. The plasma concentration of NEFA was negatively related to ADG (r=-0.63, P < 0.001), whereas that of urea correlated positively with N intake (r=0.58, P < 0.001), ruminal NH_3-N concentration (r=0.45, P < 0.001) and N excreted in urine (r=0.70, P < 0.001).

Economic analysis

The partial budget analysis of the four feeding strategies according to the proportion of field peas in concentrates is presented in Table 6. Considering the 2017 feed ingredient prices, inclusion of field peas as a substitute for soya bean meal and corn increased the total concentrate cost (€/kg) up to 5% in the 45% pea compared to the 0% pea. However, as the bulls fed the 30% pea concentrate needed to be on feed for fewer days to reach the carcass slaughter weight, their feed and yardage costs were 5% and 11% lower, respectively, than those on 0% pea. As income per carcass was equal across treatments (no relevant differences in either carcass weight or carcass quality), the difference between carcass income and the sum of feed + yardage costs resulted in better economic performance for the bulls fed the 30% pea concentrate. However, this difference was not statistically significant.

Table 7 presents the results of the sensitivity analysis about not only the cost of concentrates, but also the difference between income per carcass and the sum of feed + yardage costs in the four different scenarios. Changes in the relative costs of soya bean meal, field peas and the other ingredients resulted in different costs of the four concentrates in the four tested scenarios. Inclusion of field peas in concentrates resulted in better economic performance in terms of differences between income and feed + yardage costs compared to 0% pea in almost all the scenarios, except for the 45% pea in Scenarios 1 and 4. In Scenario 1, with the current costs at the time of the experiment, the concentrate cost increased with growing proportions of field pea but, as stated above, the bulls on the 30% pea concentrate outperformed those on 0% pea. The difference was even larger in Scenario 3 (with the maximum soya bean meal/field peas cost ratio for 2021) and Scenario 2 (with the maximum soya bean meal cost for 2022), but it was smaller in Scenario 4 (with the minimum soya bean meal/field peas cost ratio for 1991).

DISCUSSION

Animal performance

The performance observed during the whole fattening period was similar to previously reported data on young bulls fed high-concentrate diets in feedlots with either beef breeds (Blanco et al., 2008) or dairy crossbreds (Guarnido-Lopez et al., 2023). The higher gains during earlier Growing *versus* Finishing were to be expected given the composition of body gain changes with advancing physiological maturity, which increases the fat tissue share and also fat content in muscle and organs (Honig et al., 2022). Accordingly, feed efficiency decreased with increasing age and BW, which can be associated with greater fat accretion with increasing maturity and the corresponding changes in the partial efficiency of nutrient use for growth (Tedeschi, 2023).

The effect of the partial or total substitution of soya bean meal for field peas on cattle performance has been studied in different types of animals. In dairy cows, Vander Pol et al. (2008) observed similar milk yield and quality when field peas replaced soya bean meal and corn grain at the 15% inclusion rate, but indicated that, due to its limited methionine content, supplements may be necessary when feeding high-producing cows these diets. Pereira et al. (2017) found no effect on milk yield or fat content, but reported an increment in milk protein with dairy cows fed 25% field peas that were supplemented with both lysine and methionine.

The fact that there was no difference between treatments in the current experiment suggests that the amino acid content of field peas did not limit fattening bulls' performance under our conditions. This would agree with the results of Koenig and Beauchemin (2013), for whom barley-based diets containing 13% CP, such as those used here for all the treatments, sufficed to meet both microbial and host N requirements in feedlot cattle. I, agreement with our results, other experiments, in which field pea has replaced up to 40% cereals or other concentrate ingredients, report no difference in DMI, ADG or in gain/feed ratios for beef steers or heifers (Lardy et al., 2009; Jenkins et al., 2011; Greenwell et al., 2018), or even for those even on diets with relatively high forage content (Reed et al., 2004b; a; Gilbery et al., 2007; Soto-Navarro et al., 2012). The similar carcass traits among our treatments are also consistent with previously reported results in the literature (Lardy et al., 2009; Jenkins et al., 2011; Greenwell et al., 2018). However to the best of our knowledge, no studies have been conducted with intact males or intensive fattening diets with a high concentrate/forage ratio.

Ruminal fermentation parameters

Ruminal acidosis is a frequent metabolic disorder in feedlot cattle fed high concentrate, starch-rich diets (González et al., 2012) because of the high carbohydrate degradation rate and extent by ruminal microbes. Such fermentation yields a high organic acids concentration that are to be either absorbed or used for microbial synthesis. When both processes are balanced, ruminal pH is stable and often ranges from 5.8 to 6.5 in cattle already adapted to grain diets, whereas pH below 5.6 is considered suboptimal (Nagaraja and Titgemeyer, 2007). The values observed in the present experiment during both periods fall within the normal range and are far from those considered to cause subacute acidosis. This is probably because the applied concentrate feeding system allowed for frequent, small meals, which facilitate the synchronisation of feed insalivation, which acts as a buffer, and ruminal acid production and absorption (González et al., 2012).

The higher ammonia and lower VFA concentrations during Finishing that during Growing suggest an imbalance in the relative availability of N and energy, which supports the adoption of multiphase diets in which protein is reduced at the end of the fattening period to better address the daily energy and protein requirements of larger, more mature animals (Guarnido-Lopez et al., 2023). Irrespectively of the ruminal degradability of protein sources, beef finishing diets containing 12-13% CP are sufficient to meet microbial or host N requirements (Koenig and Beauchemin, 2013; Costa-Roura et al., 2020). The CP contents of our concentrates were higher, but fell within the range of those analysed by Shen et al. (2023) in a large meta-analysis of beef cattle diets.

Field peas have relatively high starch and CP contents, but these concentrations and their ruminal degradation rate may markedly vary among pea varieties (Soto-Navarro et al., 2012; Titze et al., 2021). Legume starch digestibility is lower than that of cereals, especially wheat or barley, which would keep ruminal pH stabler (Larsen et al., 2009), but ruminal degradation kinetics can also depend on particle size as affected by physical treatments (Gallo et al., 2018). Despite the similar starch content of the four concentrates, ruminal pH was lower and total VFA production was higher when concentrates included field peas. This would contradict the findings of Vander Pol et al. (2009), who found no differences in ruminal pH or VFA. However, our results corroborate those of Khorasani et al. (2001), who found a linear reduction in rumen pH and a quadratic increment in VFA with a rising level of peas in dairy cows' diet to replace soya bean meal and barley, and also those of Reed et al. (2004b), who employed field peas to replace corn in beef-growing diets. Here field peas substituted both soya bean meal and corn in concentrates, whereas barley proportion remained constant. Therefore, our results could be ascribed to the degradability of pea starch being higher than that of corn (Cerneau and Michalet-Doreau, 1991) and soya bean meal (Rotger et al., 2006).

Regarding the effect of field peas on the molar proportions of the individual VFA, the acetic and valeric acids remained unaffected, whereas propionic increased, butyric decreased, minor changes in the branched-chain VFA were observed, and the C_2:C_3 ratio tended to lower with the 30% pea concentrate. The impact of replacing other ingredients with field peas in concentrates was not consistent across studies, probably due to the different degradability of pea varieties. Our results contrast with experiments in which no differences were observed (Vander Pol et al., 2009) or where changes occurred in different directions (Khorasani et al., 2001; Reed et al., 2004b; Gilbery et al., 2007; Lobón et al., 2022). The increase in propionic acid and the concomitant trend of a lower C_2:C_3 ratio in our study corroborate the results of Yáñez-Ruiz et al. (2009) and could be explained by higher starch degradability in the concentrates that included field peas. The observed minor changes were not likely to affect microbial populations or their cellulolytic capacity (Belanche et al., 2012). Unlike the results of Romanzin et al. (2024), despite the different propionic and C_2:C_3 ratios, the FCR did not differ among treatments. This supports their hypothesis that ruminal fermentation parameters may affect, but not determine, feed efficiency.

Dietary protein is either degraded to peptides, aminoacids and ammonia, which can be used for microbial growth, or leaves the rumen as undegraded protein. Pea protein is highly soluble in the rumen and its effective degradability is higher than that of soya bean meal (Pereira et al., 2017). The higher solubility of pea protein compared to the other components that differed among the concentrates led to a higher ammonia concentration, especially in the 45% pea treatment, as previously observed in experiments with dairy (Khorasani et al., 2001; Vander Pol et al., 2009) and beef cattle (Reed et al., 2004b; Lobón et al., 2022), and also in meta-analytical studies (Mendowski et al., 2021). It has been argued that large, rapid ammonia production in the absence of sufficient energy available for microbial growth can result in its rapid absorption and may reduce N use efficiency in the rumen (Dijkstra et al., 2013). Diet fermentability can affect the supply of both microbial protein and dietary undegradable protein to the small intestine (Calsamiglia et al., 2010) and, although neither was measured here, neither ADG nor the FCR differed in the bulls fed these iso-energetic and iso-nitrogenous concentrates.

Nitrogen balance

The efficiency of N use and N excretion reduction are major concerns for both economic and environmental reasons. Non-utilised N can be partitioned between urine and faeces, and the former is more variable and more likely to reach air, soil and groundwater in the form of ammonia, nitrous oxide and nitrate (Dijkstra et al., 2013). With beef cattle, N use efficiency is low and quite variable. Recent studies indicate that it averages 26-27%, but ranges from 4% to 53% across a large number of experiments and diets depending on the growth stage, and on both protein and energy intake (Angelidis et al., 2021; Shen et al., 2023).

In the present study, total N intake and retention were higher at the end of the fattening phase. The relation between N intake and N retention during Growing was similar to that observed by Lobón et al. (2022) in an *in vivo* digestibility study with animals of the same breed and age fed the same four concentrates. This confirms that spot sampling of urine can yield similar results to the total collection for some analytical purposes, but without compromising animal welfare (Boudra et al., 2022).

The rate at which field peas were included did not affect N intake or retention, which agrees with the similar FCR herein observed, and with the similar N use efficiency in experiments in which field peas have substituted soya bean meal in dairy cattle (Froidmont and Bartiaux-Thill, 2004; Vander Pol et al., 2008). However, significant differences among treatments were found in the partition of excreted N towards urine or faeces. Despite the fact that the total VFA and ammonia production in the rumen were both higher in the treatments with the higher field pea contents, an imbalance between energy and protein supply for microbial growth seemed to result in larger ammonia losses. Absorbed excess ammonia is metabolised to urea in the liver and, although it can be partly recycled *via* saliva and the rumen wall, most is lost in urine (Bach et al., 2005), which explains the greater N excretion *via* urine in the 30% and 45% pea concentrates. This contrasts with previous studies on the impact of substituting soya bean meal for field peas in dairy cattle (Vander Pol et al., 2009; Mendowski et al., 2021), and can be explained by degradability of the pea varieties used in different studies. Substitution for other pulses, such as faba beans, does not affect faecal or urinary N losses in dairy (Cherif et al., 2018) or beef cattle (Keller et al., 2022). Koenig and Beauchemin (2013) report similar excretion in beef cattle fed diets of different protein degradabilities, but they note a significant shift towards urinary N excretion with diets of 14% vs. 12% CP content. They suggest that feeding excess protein should be avoided to reduce environmentally challenging urine N emissions. The protein content of the diets herein used fell within the range presented by Shen et al. (2023) during their fattening experiments with beef cattle. However, according to other studies on feedlot cattle (Koenig and Beauchemin, 2013; Costa-Roura et al., 2020), it could have been lowered with no major impacts on animal performance.

Plasma IGF-I and metabolites

Growth-related hormone IGF-1 followed the previously observed pattern in young bulls of the same breed during the fattening period (Blanco et al., 2010). After a sharp rise following weaning, it plateaued halfway through the fattening phase, which could be associated with the reduction in DMI in relation to BW, and resulted in smaller gains during Finishing. Plasma IGF-1 has been related to nutrient intake and protein growth (Hornick et al., 2000), and thus, lack of differences among treatments is consistent with their similar gains and FCRs.

Plasma metabolites fell within the range of the reference values described for cattle by Kaneko et al. (2008). Variations in all the metabolites were observed throughout the fattening phase, similarly to those described for young beef bulls fed high-concentrate diets up to a similar slaughter point (Blanco et al., 2020). Regarding the differences due to pea inclusion, only blood urea increased with the proportion of field peas in concentrates, which was associated with the higher ruminal degradability of pea protein and leads to increased ammonia production and absorption. After the synthesis from ammonia in the liver, urea is released to the blood pool and then excreted in body fluids like urine or milk in lactating ruminants (Calsamiglia et al., 2010). Plasma urea correlates strongly with the urea concentration in urine (Broderick and Clayton, 1997), where it constitutes the largest N share (Dijkstra et al., 2013), which agrees with the lower plasma urea and the lesser N loss in the urine of the bulls fed the 0% pea concentrate.

Economic analysis

The economic margin between income obtained per carcass and feeding + yardage costs varied by only 3% between the highest and lowest values, respectively observed in the 30% and 45% pea treatments. As carcass weight, conformation and selling price were similar across strategies, the drivers of these differences were the higher costs of concentrates in which field peas replaced soya bean meal and corn, and with the cubic response of ADG to the pea inclusion rate, i.e., daily gains increased and, consequently, days on feed dropped up to 30% pea, but the further 45% pea inclusion was detrimental to animal performance and incurred higher costs. Chen et al. (2003) found that the cost per kg gain of beef heifers increased with the level of substituting barley for field pea, whereas Greenwell et al. (2018) reported similar gain costs of during finishing when corn was partially replaced with field pea. If the cost per unit protein or energy differs between ingredients, higher costs should be compensated by either higher efficiency, as observed for up to the 30% pea inclusion, or a higher product price, which did not occur in our study (Froidmont and Bartiaux-Thill, 2004).

The profitability of intensive production systems based on concentrate-rich diets is very vulnerable to fluctuations in the price of the potential ingredients in these diets (Doyle et al., 2023). The sensitivity analysis revealed that, compared to the original costs at the time of the experiment, profitability for beef farms always remained higher in the strategies that included field peas in concentrates, and the 30% pea concentrate consistently yielded the highest margin in all four scenarios. The positive impact of including field peas increased when soya bean reached its maximum price in either absolute terms or in relation to that of field peas, but the profit lowered when the opposite happened. Similarly, Undi et al. (2024) identified that field peas could be a competitive alternative to using corn distillers and dry grains with solubles in beef diets in the given relative price scenarios. However, they also cautioned that large feed producers may be reluctant to shift from well-established, traditional ingredients if the supply and pricing of alternatives were not consistently reliable over time.

At the territory level, the competitiveness of grain legume crops in Europe and a steady supply for their inclusion in livestock feeds can be uncertain compared to other ingredients. This uncertainty could be alleviated with incentives for protein feeds and the cultivation of local pulses (Halmemies-Beauchet-Filleau et al., 2018; Rauw et al., 2023), which would fall in line with the European Green Deal. Furthermore, apart from the economic returns of including field peas in livestock diets, the agronomic and environmental effects of growing field peas should also be considered (Chen et al., 2003; Marques et al., 2022), although a full assessment of this regard is beyond the scope of the present study. Leinonen et al. (2013) found that replacing soya bean meal and cereals with legume seeds like field peas reduced the environmental impacts of poultry diets, even when considering the uncertainty of the different scenarios that they tested. However, their work lacked data about the actual impact of these diet changes on animal performance, which are crucial for assessing their potential use. Given the volatility of feed prices in recent years (Pérez-Franco et al., 2022) and the long production cycles in beef cattle, the uncertainty of commodity markets should also be taken into account to consider their inclusion in the fattening diets of cattle. For this purpose, sensitivity analyses based on the net margin or differences between prices and costs, like that herein conducted, are extremely relevant to support decisions that affect the profitability of beef farms.

CONCLUSIONS

The results of the present study generally indicate that, despite different ruminal fermentation and N use patterns, replacing soya bean and cereals with field peas did not impair the gains or feed efficiency of young bulls. They support the economic interest of including field peas up to 30% in concentrates to feed beef cattle at the cost of higher N urinary excretion, and potentially higher subsequent N emissions from manure. Hence on the territorial scale, it remains to be assessed if the greater efficiency of field pea crops in N fixation from the atmosphere in soils can offset higher N emissions from urine when fed to beef cattle.

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CRediT authorship contribution statement

I. Casasús: Conceptualization, Methodology, Investigation, Formal analysis; Writing - original draft, - review & editing; Funding acquisition. **D. Villalba**: Conceptualization, Methodology, Investigation, Formal analysis; Writing - review & editing. **M. Joy**: Conceptualization, Methodology, Investigation, Formal analysis; Writing - review & editing. **S. Costa-Roura**: Investigation, Writing - review & editing. **M. Blanco**: Conceptualization, Methodology, Investigation, Formal analysis; Writing - review & editing, Funding acquisition

Declaration of competing interest

The authors declare that they have no known competing interests.

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Table 1. Ingredients and chemical composition *(mean ± standard deviation)* of the fattening concentrates with different proportion of field pea.

	0% pea	15% pea	30% pea	45% pea
Ingredient, %				
Corn	51.60	40.60	29.59	27.04
Barley	20.00	20.00	20.00	20.00
Corn gluten feed 19%	15.00	15.00	15.00	4.41
Soybean meal 47	9.71	5.49	1.28	0.00
Peas	0.00	15.00	30.00	45.00
Palm oil	0.76	0.98	1.20	0.61
Minerals and vitamins	2.93	2.93	2.93	2.95
Chemical composition				
Dry matter (DM), g/kg	892 ± 31.1	892 ± 30.3	890 ± 30.6	889 ± 33.0
Ash, g/kg DM	57 ± 2.4	56 ± 1.7	59 ± 2.4	55 ± 2.8
Neutral detergent fibre, g/kg DM	188 ± 5.9	187 ± 9.5	193 ± 13.8	179 ± 17.8
Acid detergent fibre, g/kg DM	72 ± 6.9	79 ± 7.7	84 ± 5.9	85 ± 12.0
Lignin, g/kg DM	9 ± 2.7	9 ± 1.8	9 ± 0.8	7 ± 0.9
Crude protein, g/kg DM	147 ± 6.7	153 ± 5.2	155 ± 10	159 ± 11.4
Ether extract, g/kg DM	33 ± 3.2	34 ± 5.7	37 ± 4.5	33 ± 6.0
Starch, g/100 g DM	41 ± 8.1	40 ± 2.3	39 ± 3.5	41 ± 5.9

Table 2. Effect of the period and the proportion of pea in the concentrate on the performance (LS means ± s.e.) of young bulls.

	Period		Pea					*P-value*[1]	
	Growing	Finishing	0%	15%	30%	45%	s.e.[2]	*Period*	*Pea*
N	31	31	8	8	7	8			
Daily concentrate DMI, kg DM/d	6.30[b]±0.101	6.56[a]±0.101	6.59[ab]	6.39[ab]	6.72[a]	6.03[b]	0.172	<0.001	*0.02*
Daily DMI, g/kg $BW^{0.75}$	79[a]±0.73	65[b]±0.98	74[a]	71[ab]	75[a]	68[b]	1.5	<0.001	*0.009*
BW at start of period, kg	239[b]±4.8	444[a]±6.0	333	339	358	337	10.1	<0.001	*0.36*
ADG, kg/d	1.58[a]±0.034	1.25[b]±0.058	1.40	1.45	1.60	1.42	0.068	*<0.001*	*0.21*
Feed Conversion Ratio, kg/kg	4.0[b]±0.07	5.6[a]±0.34	5.3	4.7	4.8	4.5	0.33	*<0.001*	*0.28*

[1]The interaction was not significant

[2] pooled

Within a parameter main factor, means with different letter (a, b) differ at P< 0.05.

Table 3. Effect of the proportion of pea in the concentrate on animal traits at slaughter and the carcass characteristics.

	Pea					*P-value*
	0%	15%	30%	45%	s.e.	*Pea*
BW at slaughter, kg	508	507	507	508	1.0	*0.98*
Days on feed, d	191	182	170	187	4.9	*0.24*
Carcass characteristics						
Cold carcass weight, kg	287	287	289	285	1.6	*0.86*
Dressing percentage[1], %	56.6	56.7	56.7	56.1	0.26	*0.81*
Conformation score[2] (1-18)	10.1	10.4	10	9.8	0.25	*0.84*
Fatness score[2] (1-15)	5.8	5.4	5.7	5.6	0.13	*0.74*

[1] (Cold carcass weight/ slaughter weight) x 100

[2] Carcass conformation and Fatness score were based on a visual assessment (SEUROP classification)

Table 4. Effect of the period and the proportion of pea in the concentrate on pH, ammonia (NH_3-N) and volatile fatty acids (VFA) (LS means ± s.e.)

	Period		Pea					*P-value*[1]	
	Growing	Finishing	0%	15%	30%	45%	s.e.[2]	*Period*	*Pea*
pH	6.65 ± 0.078	6.73±0.069	7.08^{a}	6.72^{ab}	6.53^{b}	6.44^{b}	0.126	*0.20*	*0.006*
NH_3-N, mg/l	20.1^{b} ± 2.83	36.7^{a}± 3.99	21.7^{b}	22.0^{b}	25.2^{ab}	44.7^{a}	4.86	*0.002*	*0.005*
VFA total, mmol/l	116^{a} ± 3.9	97^{b}± 4.0	82^{b}	106^{a}	113^{a}	124^{a}	5.6	*<0.001*	*0.001*
Acetic acid (C_2), %	53.46^{b} ±0.672	59.96^{a}±0.703	57.97	57.08	55.1	56.69	0.963	*<0.001*	*0.26*
Propionic acid (C_3), %	34.05^{a}±1.290	22.85^{b}±0.846	24.38^{b}	27.94^{ab}	32.37^{a}	29.11^{ab}	1.702	*<0.001*	*0.03*
Butyric acid, %	8.14^{b}±0.681	13.06^{a}±0.412	12.55^{a}	11.16^{ab}	8.41^{b}	10.28^{ab}	0.861	*<0.001*	*0.02*
Iso-butyric acid, %	0.66^{b}±0.038	0.88^{a}±0.032	0.96^{a}	0.72^{b}	0.68^{b}	0.72^{b}	0.060	*<0.001*	*0.01*
Valeric acid, %	2.37^{a}±0.107	1.52^{b}±0.060	1.91	1.86	2.11	1.9	0.115	*<0.001*	*0.50*
Iso-valeric acid, %	1.32±0.271	1.73±0.126	2.24^{x}	1.24^{y}	1.31^{xy}	1.31^{xy}	0.286	*0.18*	*0.06*
C_2:C_3	1.76^{b}±0.160	2.77^{a}±0.133	2.73^{x}	2.31^{xy}	1.84^{y}	2.19^{xy}	0.223	*<0.001*	*0.07*

[1]The interaction was not significant; [2] pooled

Within a parameter main factor, means with different letter (a, b) differ at P< 0.05 and letters (x, y) differ at P < 0.10

Table 5. Effect of the period and proportion of pea in the concentrate on the nitrogen (N) balance (LS means ± s.e.)

	Period		Pea					*P-value*[1]	
	Growing	Finishing	0%	15%	30%	45%	s.e.[2]	*Period*	*Pea*
N intake, g/d	118^{b}±2.4	169^{a}±3.6	143	142	151	136	4.4	*<0.001*	*0.14*
N faeces, g/d	39.0^{b}±2.13	47.9^{a}±2.72	53.1^{a}	44.2^{ab}	38.4^{b}	38.2^{b}	3.42	*0.02*	*0.01*
N urine, g/d	13.9^{b}±0.91	22.3^{a}±1.02	14.5^{b}	18.2^{ab}	20.5^{a}	19.3^{ab}	1.53	*<0.001*	*0.04*
N retained, g/d	65.2^{b}±2.48	98.7^{a}±3.54	75.8	80.1	93.1	78.8	5.12	*<0.001*	*0.12*

[1]The interaction was not significant, [2]pooled

Within a parameter and main effect, means with different letter (a, b) differ at P < 0.05

Table 6. Economic performance during the fattening period according to the proportion of pea in the concentrate.

	Pea					
	0%	15%	30%	45%	s.e.	P-value
Total concentrate intake, kg FM	1352	1296	1238	1263	24.7	0.24
Concentrate cost, €/kg	0.219	0.223	0.226	0.230		
Yardage cost, €/d[1]	0.292	0.292	0.292	0.292		
Carcass selling price, €/kg[2]	3.94	3.94	3.94	3.94		
Feed costs, €	296	289	280	291	5.5	0.53
Yardage cost, €	55.8	53.1	49.6	54.6	1.43	0.19
Carcass income, €	1154	1154	1158	1147	6.4	0.90
Carcass income - Feed and Yardage costs, €	803	812	829	801	8.2	0.41

Actual feed, yardage and carcass prices (2017).

[1]: calculation based on days on feed, [2]: calculation based on carcass weight and conformation score (Table 2).

Table 7. Sensitivity analysis of different soybean meal and field pea cost scenarios on concentrate cost[1].

Scenario	1. Original scenario (2017)	2. Max soybean meal cost (2022)	3. Max soybean meal / field pea cost ratio (2021)	4. Min soybean meal / field pea cost ratio (1991)
Soybean meal / field pea price ratio	*1.60*	*1.37*	*1.99*	*0.76*
Concentrate price, €/kg				
0% Pea	0.219	0.357	0.233	0.178
15% Pea	0.223	0.356	0.228	0.181
30% Pea	0.226	0.356	0.222	0.185
45% Pea	0.230	0.370	0.224	0.188
Gross margin[2] *vs. 0% Pea*				
15% Pea	+1.2%	+3.9%	+3.0%	+0.9%
30% Pea	+4.6%	+11.0%	+7.9%	+3.5%
45% Pea	-0.3%	+1.3%	+3.1%	-0.7%

[1]Actual prices of all ingredients

[2]Gross margin: *Carcass income - Feed and Yardage costs*

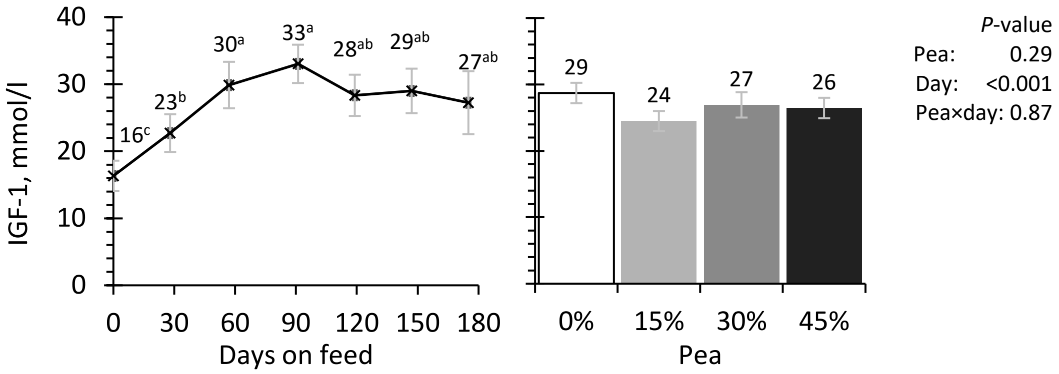
FIGURE CAPTIONS

Figure 1. Plasma IGF-I concentrations according to the days on feed and the proportion of pea in the concentrate.

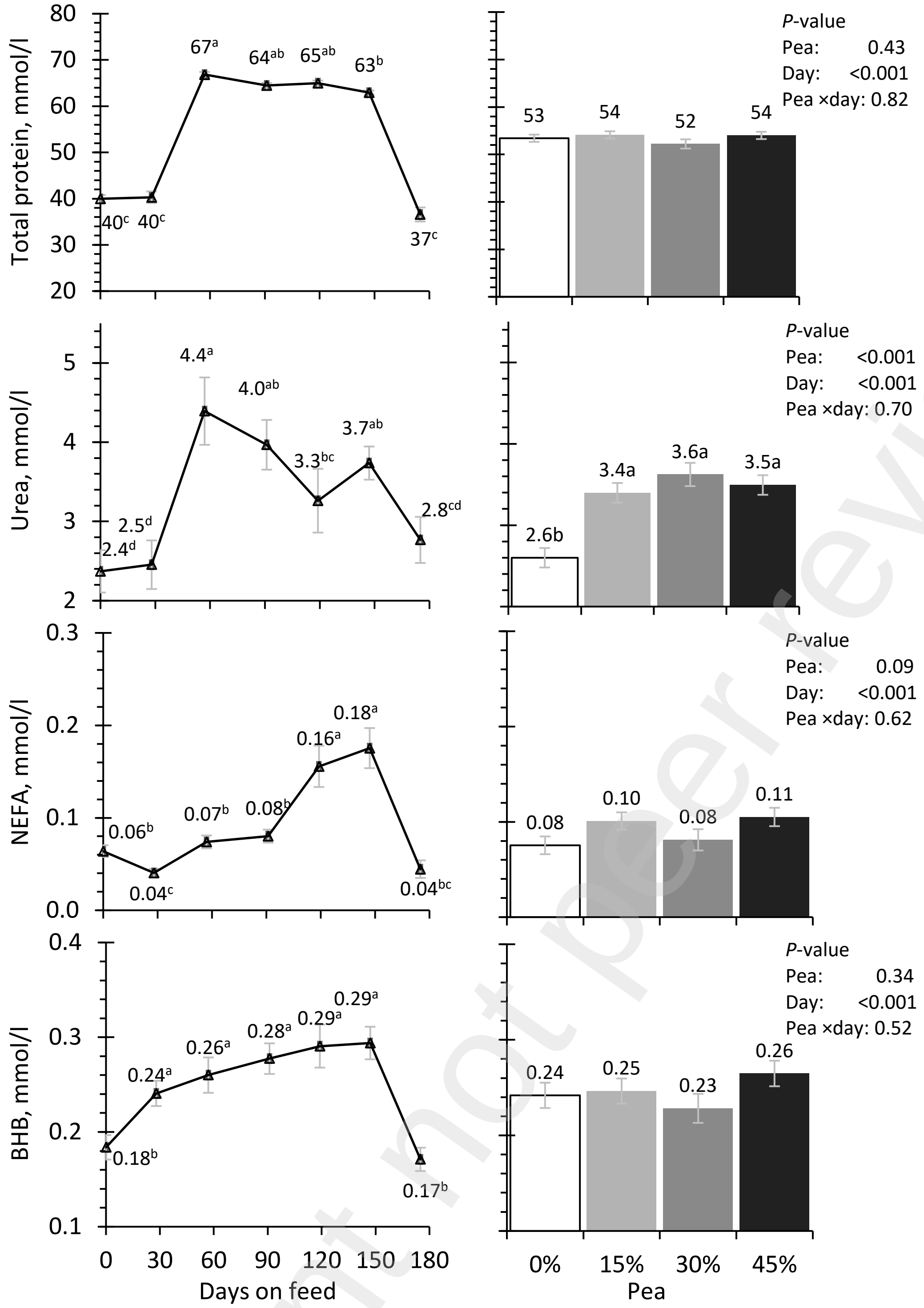
Within an effect, different superscripts (a, b, c) indicate differences at $P < 0.05$. Vertical bars indicate the standard errors

Figure 2. Plasma total protein, urea, non-esterified fatty acids (NEFA) and β-hydroxy-butyrate (BHB) concentrations according to the days on feed and the proportion of pea in the concentrate

Within a metabolite and effect, different superscripts (a, b, c) indicate differences between dates at $P < 0.05$. Vertical bars indicate the standard error



IGF-1, mmol/l
40
30
20
10
0
16c
23b
30a
33a
28ab
29ab
27ab
0
30
60
90
120
150
180
Days on feed
29
24
27
26
0%
15%
30%
45%
Pea
P-value
Pea: 0.29
Day: <0.001
Pea×day: 0.87



Total protein, mmol/l
40c 40c 67a 64ab 65ab 63b 37c
53 54 52 54
P-value
Pea: 0.43
Day: <0.001
Pea ×day: 0.82
Urea, mmol/l
2.4d 2.5d 4.4a 4.0ab 3.3bc 3.7ab 2.8cd
2.6b 3.4a 3.6a 3.5a
P-value
Pea: <0.001
Day: <0.001
Pea ×day: 0.70
NEFA, mmol/l
0.06b 0.04c 0.07b 0.08b 0.16a 0.18a 0.04bc
0.08 0.10 0.08 0.11
P-value
Pea: 0.09
Day: <0.001
Pea ×day: 0.62
BHB, mmol/l
0.18b 0.24a 0.26a 0.28a 0.29a 0.29a 0.17b
0.24 0.25 0.23 0.26
P-value
Pea: 0.34
Day: <0.001
Pea ×day: 0.52
0 30 60 90 120 150 180
Days on feed
0% 15% 30% 45%
Pea