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The Kielanowski Institute of Animal Physiology and Nutrition, Polish Academy of Sciences, Jabłonna

Influence of gender status and feeding intensity on the growth curves of body weight, dry matter intake and feed efficiency in crossbred beef cattle

C. Purwin[1], I. Wyżlic[2], P. Pogorzelska-Przybyłek[1,*], Z. Nogalski[1] and I. Białobrzewski[3]

University of Warmia and Mazury in Olsztyn, 10-719, Olsztyn, Poland
[1] Faculty of Animal Bioengineering, Department of Animal Nutrition, Feed Science and Cattle Breeding,
[2] Faculty of Animal Bioengineering, Department of Poultry Science and Apiculture,
[3] Faculty of Technical Sciences, Department of Systems Engineering

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* Corresponding author:
e-mail: paulina.pogorzelska@uwm.edu.pl

ABSTRACT. The aim of this study was to determine the effect of gender status and concentrate supplementation level on the fattening process in beef crosses with various maturity types. The animals were fattened in two dietary treatments groups differing in the level of concentrate supplementation, analogous in terms of sire breed and gender status. Feed intake was recorded. Body weight, dry matter intake and feed efficiency were analysed using the Gompertz model in 36 bulls and 36 steers, crosses of Polish Holstein-Friesian (PHF) cows and beef bulls (Hereford – HH, Limousin – LM, Charolais – CH), aged 300 to 550 days. The performance of the Gompertz model was assessed by calculating the coefficient of determination. Results showed that animals of all genotypes fed diets with a higher concentrate level were characterised by a higher growth rate. PHF × HH crosses reached their peak growth rate between 400 and 450 days of age, regardless of feeding level. On the other hand, PHF × LM crosses reached the maximum growth rate faster at the higher level of concentrate supplementation compared to the lower level (350 vs. 450 days of age). Therefore, PHF × CH bulls should be fed more intensively than steers due to the strong effect of gender status on their relative growth rate and feed efficiency. The analysis of growth curves in beef cattle can improve feed efficiency and help meet the nutrient requirements of animals at different growth stages. Predictive models could be used to estimate the breeding value of beef cattle and support selection for economically significant traits.

Introduction

Livestock growth is defined as the change in their body weight (BW) per unit of time. It is a constant function, representing life stages from embryonic development to maturity (Lawrence and Fowler, 2002). Growth curves usually assume a sigmoidal shape, with a characteristic acceleration phase, i.e. rapid growth from birth to the inflection point, marking the maximum growth rate, followed by deceleration caused by various physiological factors, until reaching a limit value (horizontal asymptote), indicating mature BW when the animal stops growing (Wilson, 1977). The shape and parameters of the growth curve can be affected by factors such as breed and population structure (particularly maturation rate), gender, feeding management, environmental conditions, and statistical methods used in the analysis (Freetly et al., 2011; Selvaggi et al., 2015). Numerous studies have compared the applicability of different mathematical models and their parameters for plotting growth curves in poultry, cattle and sheep (Selvaggi et al., 2017; Narinç et al., 2019; Demir and Sahinler, 2021; Duan et al., 2021). To ensure objectivity and accuracy of assessments, various non-linear models have been examined. Among the most frequently tested nonlinear models in cattle are the Brody, von Bertalanffy, Gompertz, Richards, and Logistic models (Tutkun, 2019; Domínguez-Viveros et al., 2020; Duan et al., 2021). The Gompertz function belongs to a family of nonlinear models that can be used to describe phenomena related to growth and development using curves (Thornley and France, 2007; Selvaggi et al., 2017). The Gompertz model has proven to be highly valuable and is most commonly used to describe growth patterns of animals (Hirooka, 2010; Liang et al., 2018; Narinç et al., 2019; Duan et al., 2021). Akbas et al. (2006) created the growth curves of crosses between beef bulls and Holstein cows, but focused solely on bulls and examined only one level of feeding intensity. In previous studies, the fattening performance of farm animals was evaluated based on mean values within groups and their variance between groups, without providing information on changes in fattening parameters over time. The available literature investigating the growth rate of crossbred animals of different breeds and genders, fed diets with varying levels of concentrate supplementation, based on a selected statistical model, is limited. Therefore, the present research hypothesis assumed that beef crosses of different maturity types could differ in fattening performance depending on gender status and the level of concentrate supplementation.

The primary objective of this study was to analyse the fattening process of bulls and steers, crosses of Polish Holstein-Friesian (PHF) cows and beef bulls (Hereford – HH, Limousin – LM, Charolais – CH). To achieve this, the Gompertz function was employed to estimate growth curve parameters related to BW, dry matter (DM) intake and feed conversion efficiency. Additionally, the study aimed to compare the responses of the examined cattle genotypes and genders to different levels of concentrate supplementation.

Material and methods

Animals and management

The study was conducted with the approval of the Ethics Committee for Animal Experimentation at the University of Warmia and Mazury in Olsztyn (Decision No. 8/2020). The experimental materials consisted of 36 young bulls and 36 steers, crosses of PHF cows and beef bulls (HH, LM, CH). The calves were fed milk replacer (Provimi, Warsaw, Poland), hay and concentrate (Cargill, Warsaw, Poland), followed by haylage. From 130 kg BW until the transfer to the fattening unit, the animals were fed grass silage *ad libitum*, which was also offered *ad libitum* during fattening, and concentrate at 2.5 kg/animal/day. Control fattening started at approximately 300 ± 5.71 kg BW, after a 30-day adaptation period in the fattening unit, and lasted for 250 ± 1.03 days. Chemical composition and nutritional value of feeds are presented in Table 1.

Table 1. Chemical composition and nutritional value of feeds

Item	Grass silage[1]	Triticale	Rapeseed meal	Concentrate
Dry matter (DM)	387.2	880.7	896.5	883.0
In DM, g kg^{-1}				
organic matter	922.4	981.4	931.1	925.5
crude protein	148.2	123.4	372.3	166.1
NDF	570.9	193	310	198
ADF	356.0	44	228	72
ADL	49.5	13	108	-
IVDMD	657.1	-	-	-
Nutritional value per kg of feed DM				
UFV, kg^{-1} DM	0.78	1.24	1.12	1.17
PDIN, g kg^{-1} DM	86.5	83.3	241.2	109.6
PDIE, g kg^{-1} DM	67.9	107.8	150.8	111.7

[1] contained (g·kg^{-1} of DM): water-soluble carbohydrates – 61.7; lactic acid – 43.5; acetic acid – 10.1; butyric acid – 4.9; (formic acid, acetic acid, propionic acid, butyric acid, isobutyric acid, valeric acid) – 18.9; N-NH_3 – 60.0; pH – 4.7; NDF – neutral detergent fibre, ADF – acid detergent fibre, ADL – acid detergent lignin, IVDMD – *in vitro* dry matter digestibility, UFV – feed unit for meat production, PDIN – protein digested in the small intestine when rumen-degraded dietary N is limiting, PDIE – protein digested in the small intestine when rumen energy available is limiting, SEM – standard error of the mean

The animals were fattened in groups, analogous in terms of sire breed and gender status, which were randomly assigned to one of two dietary treatments differing in the level of concentrate supplementation. The experimental design is presented in Figure 1.

Each diet was composed of silage with a higher (H) – 35g $kg^{-1}W^{0.75}$ or lower (L) – 25g $kg^{-1}W^{0.75}$ level of concentrate. The animals were housed in a free-stall system with free access to water and salt licks (Lisal M, KSK, Kłodawa, Poland). Feed intake was recorded individually using a Roughage Intake Control (RIC) system, two concentrate feeding stations, and an automatic animal weighing system (Insentec, Marknesse, Netherlands). The animals had *ad libitum* access to grass silage, which was administered twice daily in feed bunks (at 9:00 and

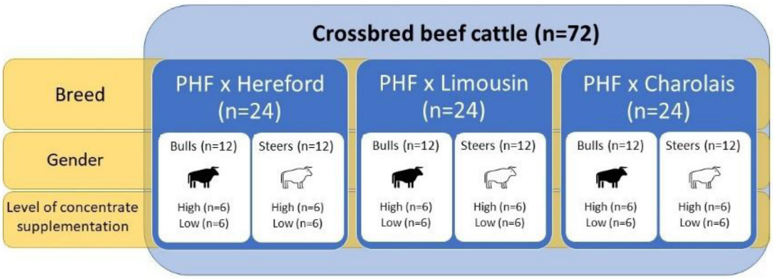

Figure 1. Experimental design.
PHF – Polish Holstein-Fresian

15:00). Silage intake was recorded individually using the RIC system (Insentec, Holland), with five animals assigned to each feed bin. The concentrate was fed separately, upon request, in rations not exceeding 1 kg, in concentrate feeding stations, where intake was recorded. The experimental silage was prepared from a mixture of first-cut grasses (*Lolium perenne, Phleum pratense, Festuca rubra, Poa pratensis*). The composition of the concentrate was as follows: up to 350 kg BW – 72.5% triticale grain, 25% rapeseed meal, and 2.5% mineral-vitamin premix (Cargill, Warsaw, Poland); above 350 kg body weight – 78.5% triticale grain, 19% rapeseed meal, and 2.5% mineral-vitamin premix. The mineral-vitamin premix contained per kg: g: 500 Fe, 235 Ca, 79 Na, 28 Mg, 48 P, 2000 Mn; mg: 3750 Zn, 375 Cu, 12.5 Co, 50 I, 12.50 Se; vitamins: IU: 250 000 vit. A, 50000 vit. D_3; mg: 909 DL-alpha tocopherol, 1000 vit. E. The concentrates were formulated based on the levels of protein digested in the small intestine, protein digested in the small intestine when rumen-degraded dietary N is limiting (PDIN), and protein digested in the small intestine when rumen energy available is limiting (PDIE). Animal body weight was determined at 14-day intervals, before morning feeding. The animals were fattened up to 550 days of age. The animals were slaughtered at the end of the fattening period. All slaughter and post-slaughter processes were carried out in accordance with the current meat industry regulations (Council Regulation (EC) No. 1099/2009 of 24 September 2009 on the protection of animals at the time of killing).

Chemical feed analyses

Chemical analyses of feeds were performed at the Laboratory of the Department of Animal Nutrition and Feed Science, University of Warmia and Mazury in Olsztyn. Silage samples were collected before and during fattening, once a month, and stored at a temperature of −25 °C. After thawing, one portion of the feed samples was dried at a temperature of 60 °C in Binder dryers and ground using a ball mill (ZM 200, Retsch, Haan, Germany) to a particle size of 1 mm to determine their proximate chemical composition (AOAC, 2012). The content of water-soluble sugars (WSC) was determined using the anthrone method described by Thomas (1977), and the content of fibre fractions (neutral detergent fibre – NDF, acid detergent fibre – ADF, and acid detergent lignin – ADL) using the method proposed by Van Soest et al. (1991). The other portion of the feed samples was not dried, and was used to determine pH using a HI 8314 pH-meter (Hanna Instruments, Olsztyn, Polska). The content of volatile acids (lactic, formic, acetic, propionic, isobutyric, butyric, and valeric acids) was measured by high-performance liquid chromatography (HPLC) using an Agilent MetaCarb 67H column (Agilent Technologies, Santa Clara, USA). The content of ammonium nitrogen was determined using the Conway method, as described by Licitra et al. (1996). *In vitro* DM digestibility (IVDMD) was determined in rumen fluid using a Daisy II incubator (ANKOM Technology Corp., Macedon, USA), followed by extraction in a neutral detergent solution according to the method proposed by Kowalski et al. (2014). Samples of concentrates and concentrate components (triticale grain and rapeseed meal) were collected simultaneously with silage samples (Polish Standard Feeds. Sampling – PN-90/R-64769). The nutritional value of the diets was determined according to the INRA system (Strzetelski, 2009), using PrevAlim 3.23 software integrated with the INRAtion 3.3 package.

Statistical analysis

The fattening performance of bulls and steers were presented based on group means and SEM (standard error of measurement), which was estimated using the following equation (1):

$$SEM = \frac{\text{standard deviation (of all samples)}}{\sqrt{\text{of all measurements in all samples}}} \quad (1)$$

The following calculations were performed to analyse growth curve parameters of BW, total DM intake, and DM intake per kg of BW gain:

– DM intake expressed as total daily intake of silage DM and concentrate DM, (kg day^{-1});
– DM intake per kg of BW gain expressed as the quotient of daily DM intake and daily gain, kg kg^{-1} day^{-1}.

The Gompertz double exponential function was applied using the following equation (2) (Seber and Wild, 1989):

$$x(t)=A+Ce^{-e^{-B(t-M)}} \tag{2}$$

where: – dependent variable, t – time, A – (asymptote) at t ->0, C – difference between the upper asymptote and the lower asymptote, B – relative rate at M, M – time when the maximum absolute rate is observed.

The coefficients A, C, B, M in the Gompertz model were determined using the *fmincon* optimisation procedure implemented in the MATLAB R2014a package (MathWorks, USA).

The rate of change in BW was calculated as the derivative of the BW function described by the Gompertz equation. Growth curves for the analysed parameters were presented graphically using a Sigma Plot 12.0 software (Systat Software Inc.). The coefficient of determination (R2) (square of the r-Pearson correlation coefficient) was also calculated to assess the goodness-of-fit of the model (the proportion of variance in the dependent variable explained by the model).

Results

Table 2 presents the fattening performance of bulls and steers, based on group means. Additionally, Figures 2, 3, and 4 illustrate the changes in fattening parameters over time for the analysed beef crosses. The effects exerted by model parameters, i.e. gender status and concentrate supplementation level were determined. Figures 5a and 5b compare the response of cattle breed groups to varying feeding intensities.

The analysis of the fattening process of PHF × LM bulls and steers at two levels of concentrate supplementation revealed that bulls gained weight faster than steers at the beginning of fattening, but the growth rate of steers exceeded that of bulls at 330 and 350 days of age in groups receiving diets with the lower and higher concentrate level, respectively (Figure 2a; A). The highest growth rate of steers fed silage with the higher concentrate level was attributed to their highest feed intake, which was observed in this group throughout fattening (Figure 2b; C). Feed efficiency in steers fed silage with the higher concentrate level remained constant from the beginning of fattening to 500 days of age (Figure 2b; D). Their relative growth rate (Figure 2a; B) was also highest from 350 days of age until the end of fattening compared to all PHF × LM crosses. PHF × LM bulls fed more intensively up to 350 days of age showed the highest rate of changes in BW, the highest relative growth rate (0.35% BW), and the highest feed efficiency. In all groups of PHF × LM crosses, excluding steers fed less intensively, the highest relative growth rate was recorded at the beginning of fattening, when BW was lowest (Figure 2b; B).

PHF × CH bulls and steers (Figure 3a) fed diets with the higher concentrate level were characterised by a higher rate of BW changes (up to approx. 420 days of age in steers and until the end of fattening in bulls). Steers reached their maximum daily gains at approximately 350 days of age, and then their rate of gain declined sharply with a decrease in feed efficiency from day 420 onwards (Figure 3b; D). Feed intake was highest in this group throughout the fattening period (Figure 3b; C). BW of bulls increased

Table 2. Effect of sire breed, gender status, and concentrate supplementation level on the fattening performance of crossbred bulls and steers

Item	PHF × LM				PHF × CH				PHF × HH				SEM
	bulls		steers		bulls		steers		bulls		steers		
	L	H	L	H	L	H	L	H	L	H	L	H	
Days of fattening	250	249	251	250	251	248	250	250	248	250	251	250	1.18
Initial body weight, kg	295	297	286	297	289	291	287	300	293	305	293	300	3.86
Final body weight, kg	523	543	517	569	501	554	534	554	521	597	551	580	9.71
Dry matter intake, kg/day	7.2	7.8	6.7	9.0	6.9	8.1	7.3	8.3	7.2	8.5	7.4	8.9	0.22
Dry matter intake/kg of body weight gain, kg	7.9	7.9	7.2	8.3	8.1	7.7	7.4	8.2	7.9	7.3	7.2	7.9	0.18
Total gain, kg	228	246	231	272	212	263	247	254	228	292	258	280	8.3
Daily gain, g	916	984	928	1088	848	1052	988	1016	912	1168	1032	1120	31.2

PHF × LM – crosses of Polish Holstein-Friesian cows and Limousin bulls, PHF × CH – crosses of Polish Holstein-Friesian cows and Charolais bulls, PHF × HH – crosses of Polish Holstein-Friesian cows and Hereford bulls, L – diet with a low level of concentrate supplementation, H – diet with a high level of concentrate supplementation, SEM – standard error of the mean

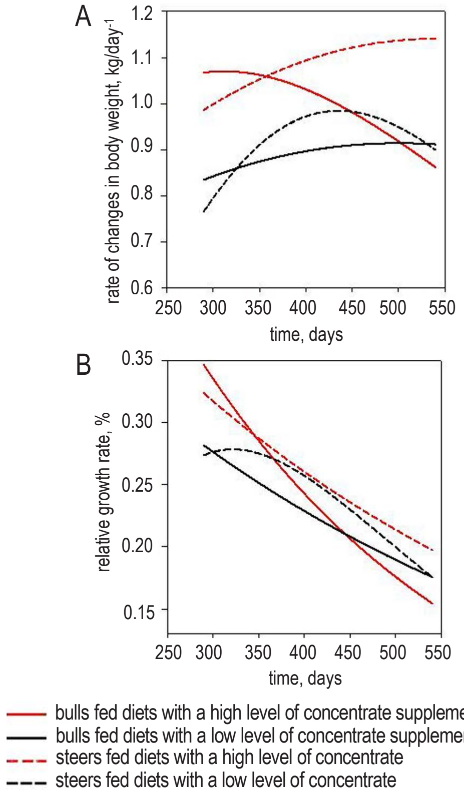

Figure 2a. Rate of changes in body weight (A) and relative growth rate (B) of crosses between Polish Holstein-Friesian cows and Limousin bulls (PHF × LM)

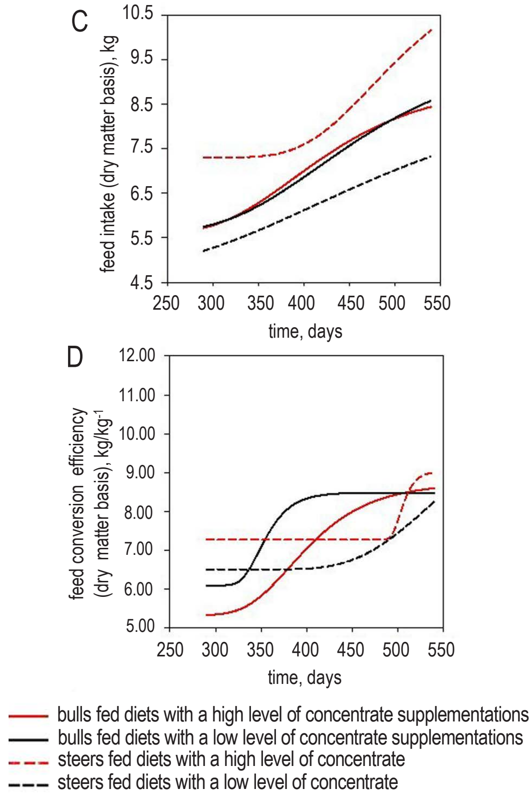

Figure 2b. Feed intake (C) and feed conversion efficiency (D) (dry matter basis) in crosses between Polish Holstein-Friesian cows and Limousin bulls (PHF × LM)

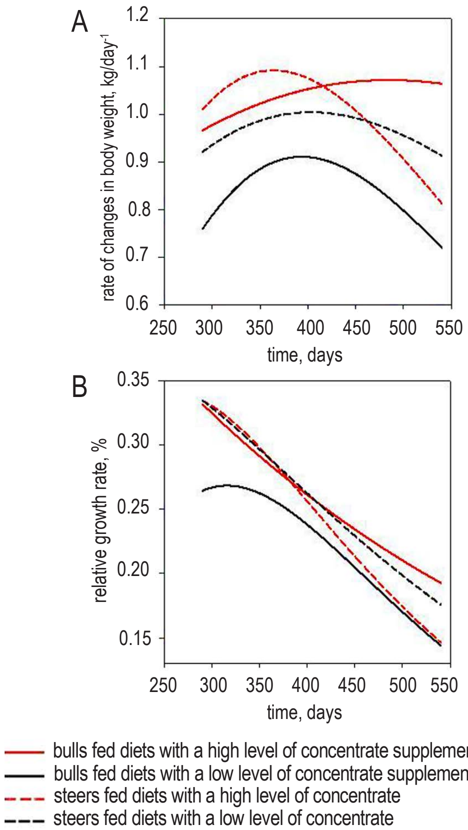

Figure 3a. Rate of changes in body weight (A) and relative growth rate (B) of crosses between Polish Holstein-Friesian cows and Charolais bulls (PHF × CH)

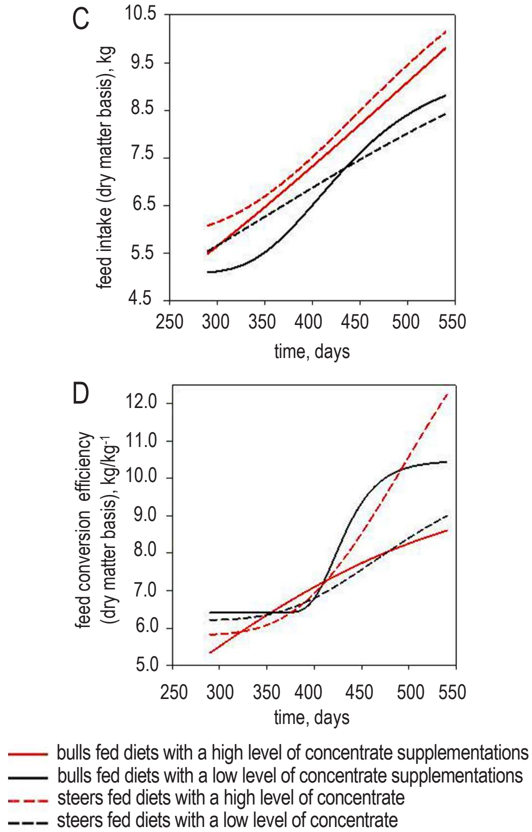

Figure 3b. Feed intake (C) and feed conversion efficiency (D) (dry matter basis) in crosses between Polish Holstein-Friesian cows and Charolais bulls (PHF × CH)

progressively to 450 days of age, and remained highest until the end of fattening compared to all PHF × CH crosses. When diets with the lower concentrate level were administered, the rate of BW changes was higher and slower in steers compared to bulls. Both bulls and steers reached their peak growth rate at about 400 days of age, but it was approximately 0.1 kg lower in bulls than in steers.

The analysis of the fattening process of PHF × HH bulls and steers using the Gompertz double exponential function (Figures 4a and 4b) demonstrated a very strong effect of gender status on the rate of BW changes. PHF × HH steers were characterised by a similar rate of BW changes over time, and they reached their maximum daily gains between 350 and 400 days of age. The growth rate of steers was higher than that of bulls up to 370 and 470 days of age when diets with the higher and lower level of concentrate supplementation were fed, respectively (Figure 4a; A). Feeding intensity exerted a significantly stronger effect on the rate of BW changes over time in PHF × HH bulls than in steers. The higher concentrate level contributed to a considerably higher growth rate of bulls throughout the analysed period. Bulls fed more intensively reached their peak growth rate at approximately 450 days of age, while those fed less intensively reached a peak at the end of fattening. The rate of changes in feed intake was highly similar in all PHF × HH crosses (Figure 4b; C). Feed intake was significantly affected by the level of concentrate supplementation, whereas it did not differ between bulls and steers at the same level of feeding intensity. The analysis of DM intake per kg of BW gain (Figure 4b; D) demonstrated that steers in the more intensive feeding regime required more feed than bulls from day 400 onwards, whereas steers in the less intensive feeding regime had lower feed efficiency from day 480 onwards.

The analysis of the effects of breed and feeding intensity on fattening performance revealed that crosses of all genotypes fed more intensively showed higher growth rates throughout the fattening period (Figure 5a; A). The greatest differences were recorded in PHF × HH crosses. Their growth rate was lower at the beginning of fattening, but they outperformed PHF × CH and PHF × LM crosses at 300 and 350 days of age in groups receiving diets with the higher and lower concentrate level, respectively.

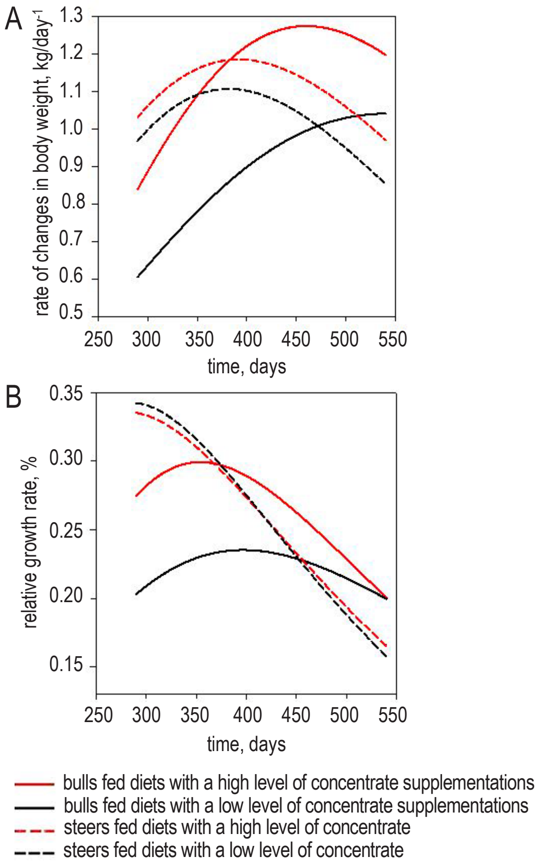

Figure 4a. Rate of changes in body weight (A) and relative growth rate (B) of crosses between Polish Holstein-Friesian cows and Hereford bulls (PHF × HH)

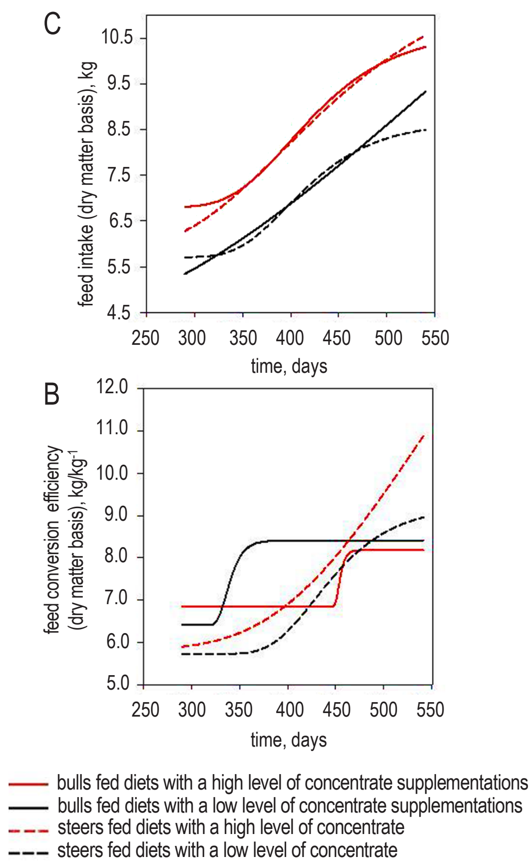

Figure 4b. Feed intake (C) and feed conversion efficiency (D) (dry matter basis) in crosses between Polish Holstein-Friesian cows and Hereford bulls (PHF × HH)

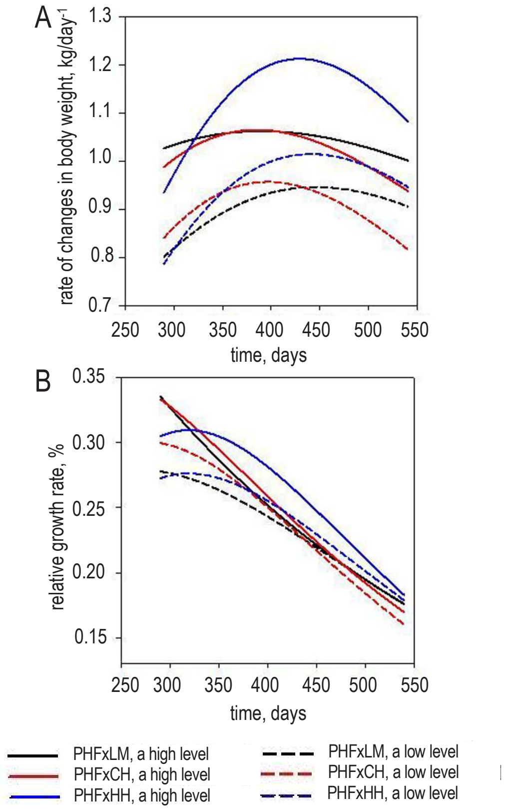

Figure 5a. Comparison of the rate of changes in body weight (A) and relative growth rate (B) of crosses between Polish Holstein-Friesian cows and Limousin, Charolais and Hereford bulls (PHF × LM, PHF × CH and PHF × HH, respectively) depending on feeding intensity

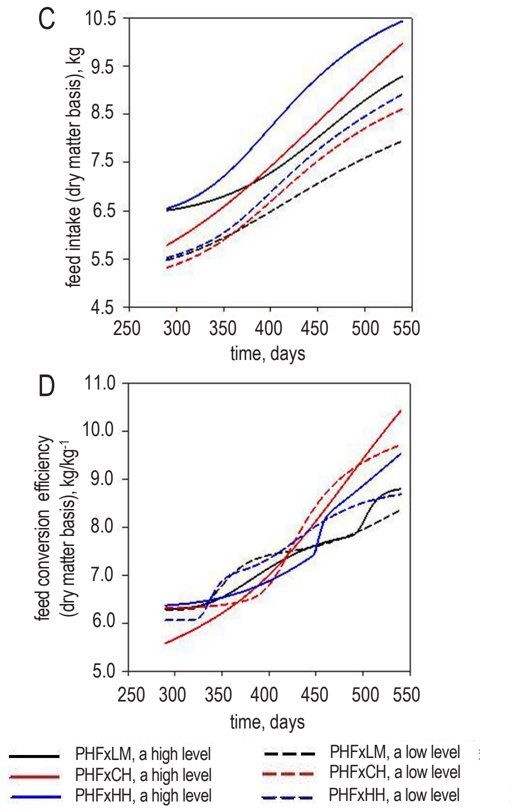

Figure 5b. Comparison of feed intake (C) and feed conversion efficiency (D) (dry matter basis) in crosses between Polish Holstein-Friesian cows and Limousin, Charolais and Hereford bulls (PHF × LM, PHF × CH and PHF × HH, respectively) depending on feeding intensity

PHF × HH crosses reached their maximum growth rate within the shortest time (between 400 and 450 days of age), irrespective of the level of concentrate supplementation, whereas PHF × LM crosses reached their peak growth rate faster in the more intensive feeding regime (350 vs. 450 days of age) (Figure 5a; B). When silage was supplemented with the higher level of concentrate, all crosses reached their maximum growth rate at a similar time. At the lower level of feeding intensity, PHF × CH crosses reached their peak growth rate approximately 100 days earlier than PHF × LM animals. The analysis of feed intake (Figure 5b; C) indicated that the higher level of concentrate supplementation contributed to increased DM intake in all animals, which was highest in PHF × HH crosses and lowest in PHF × LM crosses throughout the fattening period. Larger differences in daily DM intake were recorded from 350 days of age onwards.

The feed efficiency curves (Figure 5b-D) showed the most similarity among all groups compared to feed intake and BW curves. The greatest differences were observed in PHF × CH crosses fed more intensively. In this group, DM intake per kg of BW gain was lowest from the beginning of fattening to 370 days of age, and highest from day 500 onwards. A significant increase in DM intake per kg of BW gain was followed by a linear shape of the curve from day 450 onwards. PHF × LM crosses showed the smallest differences in this parameter between the beginning and end of fattening. In all genotypes, animals from 500 days of age onwards fed silage supplemented with the higher level of concentrate required more feed (DM basis) per kg of BW gain than their counterparts fed less intensively.

Changes in the fattening parameters of crossbred bulls and steers were analysed using the Gompertz model, and the model's goodness-of-fit was assessed by calculating the coefficient of determination (Tables 3 and 4). Double exponential functions most accurately described the rate of changes in BW of cattle, where the coefficient of determination reached 1.000 in all groups, with the exception of PHF × HH crosses fed less intensively ($R^2 = 0.999$). The goodness-of-fit of the model was also high for feed intake ($R^2 = 0.782 – 0.909$), and lowest for feed efficiency ($R^2 = 0.495 – 0.878$). The fattening process was described least accurately for PHF × LM crosses fed diets with the lower level of concentrate supplementation.

Table 3. Coefficient of determination (R^2) for fattening parameters in bulls and steers in relation to experimental factors

Sire breed	Gender status	Concentrate supplementation level	R^2		
			Rate of changes in body weight	Dry matter (DM) intake	Feed conversion efficiency, DM basis
Hereford	Bulls	High	1.000	0.894	0.632
		Low	0.999	0.881	0.303
	Steers	High	1.000	0.921	0.931
		Low	1.000	0.891	0.830
Limousin	Bulls	High	1.000	0.841	0.903
		Low	0.999	0.816	0.659
	Steers	High	0.999	0.834	0.345
		Low	1.000	0.748	0.331
Charolais	Bulls	High	1.000	0.895	0.853
		Low	1.000	0.925	0.924
	Steers	High	1.000	0.924	0.883
		Low	1.000	0.846	0.832

Table 4. Coefficient of determination (R^2) for fattening parameters in bulls and steers in relation to sire breed and concentrate supplementation level

Sire breed	Concentrate supplementation level	R^2		
		Rate of changes in body weight	Dry matter (DM) intake	Feed conversion efficiency, DM basis
Hereford	High	1.000	0.907	0.781
	Low	0.999	0.886	0.567
Limousin	High	1.000	0.837	0.624
	Low	1.000	0.782	0.495
Charolais	High	1.000	0.909	0.868
	Low	1.000	0.886	0.878

Discussion

Assessments of the biological efficiency of cattle should not rely solely on body weight (BW) (Goyache et al., 2003) as genotypes with faster growth rates may not always be more efficient than slower-growing individuals of the same mature size. Feed costs may be higher in fast-growing cattle than in slower-growing animals (Akbaş et al., 2006). However, animal growth should be analysed by considering feed intake and feed efficiency, as changes in the shape of growth curves may result from differences in feed intake patterns. Nutrition generates the highest costs in beef production. Nutrition constitutes a major cost in beef production, and research has shown that feed intake is a hereditary trait with significant genetic variability among beef cattle breeds (Fan et al., 1995). Esfandyari and Jensen (2021) estimated the heritability of feed intake in growing animals in the moderate range of 0.25 and 0.44. One of the objectives of beef cattle breeding programmes is to optimise production efficiency and profitability by improving the feed conversion ratio (FCR). Therefore, feed efficiency is an important criterion of cattle classification by beef producers (Rezende et al., 2022).

The results of this study indicated that gender status exerted a strong influence on the rate of BW changes and the relative growth rate of crossbred beef bulls and steers fed diets with high and low levels of concentrate supplementation (H and L, respectively). The above effect was particularly evident in the relative growth rate of crosses between PHF cows and early-maturing HH bulls. Based on the feed efficiency criterion, it is highly recommended to finish PHF × HH steers on diets with a lower level of concentrate supplementation (up to 25 g $kg^{-1}W^{0.75}$), as they should only be fed intensively up to 450 days of age. However, PHF × HH bulls need to be fed intensively from 330 to 550 days of age in order to optimise their growth and feed efficiency. In the present study, this group of animals achieved the highest total and daily gains (292 kg and 1168 g/day, respectively) of all experimental groups. The high production potential of Herefords was also previously described by Fan et al., (1995) and Manninen et al., (2011). In the study by Manninen et al., (2011), Hereford bulls fed high-moisture grass silage with a D-value of 750 g/kg^{-1}, supplemented with concentrate at 3.2 kg DM/day^{-1}, had daily gains of 1588–1808 g. The above results suggest that the Hereford breed and its crosses are well adapted to a grass silage-based fattening system, and can achieve high weight gains in extensive beef cattle feeding systems when fed diets with a higher proportion of concentrate.

The analysis of changes in feed efficiency in crosses between PHF cows and late-maturing CH bulls revealed that, unlike PHF × HH crosses, steers should be fed intensively up to 400 days of age. As regards fattening performance, the most appropriate feeding strategies for PHF × CH crosses should involve more intensive feeding of bulls and less intensive feeding of steers. The prediction and monitoring of alterations in fattening parameters over time can help reduce the costs of beef cattle breeding, mainly feed costs, by managing individual animals in the herd separately (Duan et al., 2021).

In PHF × LM crosses, more intensive feeding up to 520 days of age improved feed efficiency in bulls, whereas in steers, this strategy increased feed intake per kg of BW gain. Akbaş et al., (2006) analysed Friesian (F), Limousin × Friesian (Li × F), and Piemontese × Limousin (Pi × F) cattle and found no differences in DM intake curve parameters between genotypes, while observing a significant effect of genotype on total gains. The cited authors also noted positive coefficients of correlation between BW and DM intake in all genotypes. These findings suggest that an increase in DM intake is a result of increasing BW. Animals that mature later tend to have higher DM intake, and the later an animal reaches maximum DM intake, the higher its BW. In the latter study, the age at the inflection point (slowdown after a period of intensive growth) of F, Li × F and Pi × F bulls was 245, 270, and 227 days, respectively. This may suggest that in the present study, most animals reached their maximum relative BW gain prior to the start of observation.

The analysis has confirmed that changes in BW of animals are affected by genetic and environmental factors, leading to specific growth patterns in each population and breed of cattle (Domínguez-Viveros et al., 2020; Hozáková et al., 2020). The current study applied the Gompertz model to analyse the rate of changes in BW, relative growth rate, DM intake, and feed conversion efficiency. Notably, the values of the coefficient of determination for the rate of BW changes (R^2 = 0.009 – 1.000) were higher in all crosses compared to those reported for Holstein bulls – 0.998 (Tutkum, 2019), Podolica bulls – 0.996 (Selvaggi et al., 2017), Nellore bulls – 0.916 (Fernandes et al., 2012) and Chinese Simmental beef cattle – 0.954 (Duan et al., 2021).

Analysing the growth curves of beef cattle can be highly beneficial in implementing more effective feeding strategies and meeting the specific nutrient requirements of animals at each growth stage. Predictive models could be used in practice by cattle breeders and producers to effectively detect and adequately respond to slower growth stages in order to achieve weight-for-age targets. Growth curve parameters could be used to estimate the breeding value of beef cattle and support selection for economically important traits.

Conclusions

Double exponential functions most accurately described the rate of changes in cattle body weight, and the fattening process was described least accurately in Polish Holstein-Friesian (PHF) × Limousin (LM) crosses fed diets with the lower level of concentrate supplementation. PHF × Hereford (HH) crosses reached peak growth rates faster that PHF × Charolais (CH) and PHF × LM crosses. The former also maintained the highest relative growth rate at both feeding levels and were characterised by the highest DM intake throughout the fattening period. The changes in this parameter observed in PHF × LM crosses indicated that they required a longer period of fattening and a lower level of concentrate supplementation. Gender status exerted a strong effect on the relative growth rate and feed efficiency, which suggests that PHF × HH steers should be fed intensively up to 450 days of age, whereas PHF × HH bulls from 330 days of age until the end of fattening. Furthermore, PHF × CH bulls should be fed more intensively than PHF × CH steers.

Conflict of interest

The Authors declare that there is no conflict of interest.

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