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Comparison of Nonlinear Models to Describe the Growth Curves of Jaffarabaddi, Mediterranean and Murrah Buffaloes

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ABSTRACT

Knowledge of buffalo growth curves is essential for improving reproductive management, nutritional strategies and identifying the best slaughter age. We provided the first joint study comparing growth curves of the three major buffalo breeds. Additionally, we used principal component analysis and Biplot graphics to evaluate the degree of similarity between the groups (breed by sex) and their relationship with mature weight, maturation rate and weight at different ages. The dataset included 8,550 weight records from 1,391 Jaffarabadi, Mediterranean and Murrah buffaloes. The Bertalanffy model had the best fit. The mature weights were 696.64±8.50 and 678.53±9.44 kg (Mediterranean), 716.26±48.54 and 629.28±32.11 kg (Jaffarabadi) and 694.69±17.97 and 556.53±15.49 kg (Murrah) male and female, respectively, by Bertalanffy model. All breeds reaching 75% of mature weight in less than two years. Murrah females were particularly productive, having high precocity and low weight maturity - important biotypes for milk production. Murrah males showed intermediate characteristics, and high potential for meat production in dairy herds. Mediterranean animals showed high weight gain, median precocity and medium to high weight at maturity, supporting its status as the main breed for beef production in Brazil. Jaffarabadi males had high mature weight, slow growth in the first year of life followed by high growth thereafter. Female Jaffarabadi were smaller and showed a similar level of precocity to Mediterranean animals. Buffaloes in Brazil have traditionally been used for milk production; however, our study clearly demonstrates that all three breeds have appropriate characteristics for meat production.

Keywords: Maturation rate, Mature weight, Meat production, Principal component analysis.

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INTRODUCTION

Buffaloes are used throughout the world as working animals, and for the production of meat and milk. In Brazil, buffaloes predominantly fulfill the dual purpose of meat and milk production (Malhado *et al.*, 2013). Among the three principal buffalo breeds in Brazil (Murrah, Jaffarabadi and Mediterranean), Murrah herds are mainly selected for milk production and Mediterranean animals for meat production. In contrast, Jaffarabadi herds do not have a well-defined purpose type. More generally, although many buffalo herds (especially Murrah) are raised for milk production, there is great potential for meat production (Alves and Franzolin, 2015).

Growth characteristics clearly have an important effect on the commercial value of livestock. For example, the value of buffaloes when they are sent to the slaughter depends to a large degree on the amount of muscle on the carcasses; body weight is

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strongly associated with other economically important characteristics, including production and reproduction traits (Salem *et al.,* 2013). Thus, selection programs that change growth in cattle will also cause permanent changes in associated traits.

Nonlinear mathematical functions, empirically developed by plotting body weight against age, have been shown suitable to describe the growth curve of many different species (Wurzinger *et al.*, 2005; Malhado *et al.*, 2009; Osei-Amponsah *et al.,* 2011; Lopes *et al.,* 2012; Fradinho *et al.,* 2016). Such models are a good way of condensing the information contained in a temporal data series into two parameters with biological meaning that can be used for inter-species or inter-breed comparisons.

There have been several studies assessing growth curves in Buffaloes (Malhado *et al.*, 2008; Ramos *et al.,* 2007; Agudelo-Gómez *et al.,* 2009; Araújo *et al.,* 2012; Alves and Frazolin, 2015). However, here we compared growth curves of the three major buffalo breeds from South America. Furthermore, we use principal component analysis and Biplot graphics to evaluate the degree of similarity between the groups (breed by sex) and their statistical relationship with the following parameters: (i) Mature weight; (ii) Mmaturation rate; (iii) Weight at 205 days (W205); (iv) Weight at 365 days (W365), and (v) Weight at 550 days (W550).

MATERIALS AND METHODS

The dataset included 8,550 weight records which were collected from 1,391 buffalos related to nine herds (4, 4 and 1 herds for Murrah, Mediterranean and Jaffarabadi, respectively) from 2008 to 2012 (Table 1). Each animal had at least five weight records (since the birth until 900 days of age).

The functions Brody ($y = A(1 - Be^{-kt}) + \varepsilon$), Von Bertalanffy ($y = A(1 - Be^{-kt})^3 + \varepsilon$), Richards ($y = A(1 - Be^{-kt})^{-m} + \varepsilon$), Logistic ($y = A(1 + e^{-kt})^{-m} + \varepsilon$) and Gompertz ($y = Ae^{Be^{-kt}} + \varepsilon$) were adjusted to estimate the growth and the curve parameters, where *Y* represents the body weight at age *t*; *A* represents the asymptotic weight; *B* is the integration constant. The *B* value is determined by the initial values of *Y* and *t*; *k* refers to the maturation rate, and *m* is the parameter shaping the curve.

In contrast to linear models, nonlinear models have a more complicated dependence on the fitting parameters that usually precludes a direct solution. Thus, model fitting relies on iterative methods such as the Gauss-Newton algorithm. This process was accomplished by using the NLIN procedure (SAS, 2001).

The criteria adopted to select the best model to describe growth curve were: (1) Coefficient of determination (R^2)– calculated through a linear regression analysis between observed and estimated weights, considering the predicted weight by the function as a dependent variable and the observed weight as an independent variable; (2) The convergence percentage (C%)– considering whether there is convergence or not, and (3) Absolute Mean Residual Deviation (MAD), calculated as:

Table 1. Number, sex, Birth Weight (BW), Weights at 205 (W205), 365 (W365) and 550 (W550) days of age within each breed (all weights in kg).[a]

Genetic group	Number	Male	Female	BW	W205	W365	W550
Jaffarabadi	88	44	44	36.43^c	170.07^c	298.17^b	388.86^b
Mediterranean	887	520	367	39.79^a	198.48^a	315.80^a	427.93^a
Murrah	416	241	175	37.63^b	179.60^b	280.77^c	363.79^c

[a] Means with different letters are significantly different (P< 0.05).

$$MAD = \frac{\sum_{i=1}^{n} | Y_i - \hat{Y}_i |}{n}$$

Where Y_i is the observed value, $\hat{Y}_i$ is the estimated value and n is the sample number. After selecting the most appropriate function, we calculated Absolute Growth Rate (AGR) based on the first derivative from the adjusted function in relation to time ($\partial Y / \partial t$). The *AGR* represents the weight gained per time unit. In this case, this equals the daily weight gain estimated throughout a growth period and corresponds to the mean animal growth rate within a population. Additionally, the inflexion point (weight and time) and the degree of maturity were calculated following Brown *et al*. (1976).

The associations between the curve parameters (A and K) and the adjusted weights were calculated by linear Pearson correlation. In a second step, the parameters *A* and *K* (from the best model fit) and W205, W365 and W550 were considered as variables in a Principal Component Analysis (PCA) using the software PAST. This method aims to construct new random variables that are linear combinations (major components) of the original *p* variables (Johnson and Wichern, 2007). From these variables it is possible to construct p main components, using the first k principal components that satisfactorily explain the proportion of the original variance for the problem under study (k< p) (Johnson and Wichern 2007).

With the estimation of the major components it is possible to construct Biplot graph: a graphical representation of a matrix X of approximate data for a matrix A dimension smaller. The Biplot represents each line as a point G_n with coordinate (g_{i1}, g_{i2}), i= 1, · · ·, n, and each column a vector starts at the origin to the point H_m with a coordinate (h_{j1}, h_{j2}), j= 1, · · ·, p, in a two-dimensional graph, i.e., the vectors represent the variables (A, K, W205, W365 and W550) and the points represent the groups (breed by sex).

RESULTS AND DISCUSSION

Based on the determination coefficient (R^2) and considering all animals, the Bertalanffy and Brody models had the best fit, reaching up to about 92% (Table 2). When the animals that have not converged or which had values outside of biological reality were removed from the data set, the R^2 values were higher than 98% for all models. For convergence percentage, the Brody (33.77%) and Bertalanffy (89.05%) models had the lowest and highest values, respectively. The Mean Absolute Deviation (MAD) values were in agreement with R^2 and convergence percentage criteria, indicating that the Bertalanffy function has the best fit.

Malhado *et al.* (2008) studying Murrah buffalos reported the superiority of Logistic, Gompertz and Bertalanffy models (in descending fit order) to estimate growth. Agudelo-Gómez *et al.* (2009) concluded that growth curve of Colombian buffalo cattle was better described by Brody and

Table 2. Estimates of the parameters *A*, *B*, *k* and *m*, determination coefficient (R^2), Convergence percentage (C%) and Mean Absolute Deviation (MAD) according to each function for all genetic groups.

Model	Parameters				R^{2a}	R^{2b}	*C (%)*	*MAD*
	A	*B*	*k*	*m*				
Bertalanffy	671.95	0.612	0.0032	-	93.3	99.0	89.05	5.09
Brody	651.61	0.927	0.0026	-	92.9	96.1	33.77	13.11
Gompertz	597.54	2.583	0.0044	-	77.63	99.0	80.47	9.37
Logistic	567.21	-	0.0054	3.61	77.01	99.1	76.38	10.01
Richards	650.12	0.929	0.0803	0.03	87.1	98.6	37.59	10.99

[a] For all animals, [b] Animals that do not converge and outside the biological reality were excluded.

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Gompertz curves. However, Araújo *et al.* (2012) recommended Gompertz and Logistic models for Murrah buffaloes (male and female). Soysal *et al.* (2015) reported that Richards and Bertalanffy models are the most appropriate for female and male Anatolian buffalos, respectively. These studies indicate that the same function might produce variable results according to the breed, population or feature tested, and that they consequently need to be tested prior to model selection (Malhado *et al.*, 2009). Thus, despite the Bertalanffy function having the best overall fit (for all breed and sex), the results would probably be different if each breed/sex was analyzed separately.

Parameter *A* represents an estimate of the asymptotic weight, interpreted as weight at maturity. This value does not represent the maximum animal weight, but rather the mean seasonal-free weight at maturity. The definition of an optimum adult weight is controversial, since it depends on the species, breed, selection method, management system and environmental conditions (Malhado *et al.*, 2009).

When the estimates of parameter *A* among the males of the three breeds were compared, the highest value was identified in the Jaffarabadi breed (716.26±48.54 kg), followed by Mediterranean (696.64±8.50 kg) and Murrah (694.69±17.97 kg) breeds. However, no significant differences (P> 0.05) were found between male animal of studied breeds (Table 3).

The means of the parameter *A* for females were 678.53±9.44, 629.28±32.11 and 556.53±15.49 kg for the Mediterranean, Jaffarabadi and Murrah breeds, respectively, by the Bertalanffy model. The Jaffarabadi females were significantly different (P< 0.05) from Murrah females (Table 3). The greater heterogeneity of the Jaffarabadi breed is explained by the existence of two distinct varieties in Brazil, the Gir, of lower body form structure and Palatina with larger structure and higher adult weight. The literature reports maturity weight (A) ranging from 426 to 625 kg in the Murrah breed using Bertalanffy models (Malhado *et al.*, 2008; Araújo *et al.*, 2012) and from 567 to 591 kg in the Mediterranean breed using Logistic models (Alves and Franzolin, 2015). No information on the growth curve of the Jaffarabadi breed was found in the literature.

The *k* parameter (representing maturation rate) indicates the growth speed to achieve the weight at maturity. Animals with high *k* values show a precocious maturity in relation to those with lower *k* values and similar initial weight (Malhado *et al.*, 2009). The *k* estimates were significantly higher (P< 0.05) in female Murrah than in female Jaffarabadi and Mediterranean individuals. Murrah males also had higher *k* estimates, though not significantly different from the other breeds (P> 0.05) (Table 3).

Table 3. Parameter estimates (*A*, *k* and *B*) obtained by Von Bertalanffy function for the Jaffarabadi (JAF), Mediterranean (MED) and Murrah (MUR).

Breed	Parameters [a]				
	A	*k*	*B*	Inflexion Time (Days)	Inflexion Weight (kg)
Male					
JAF	716.26^{a}±48.54	0.00294^{b}±0.0001	0.681±0.04	242.99	212.22
MED	696.64^{a}±8.50	0.00322^{b}±0.0001	0.613±0.00	189.19	206.41
MUR	694.69^{a}±17.97	0.00329^{ab}±0.0002	0.612±0.00	184.18	205.83
Female					
JAF	629.28^{ab}±32.11	0.00322^{b}±0.0001	0.605±0.02	185.11	186.45
MED	678.53^{a}±9.44	0.00312^{b}±0.0001	0.614±0.00	195.78	201.04
MUR	556.53^{b}±15.49	0.00363^{a}±0.0002	0.587±0.00	155.89	164.89

[a] Means inside sex with different letters are significantly different (P< 0.05).

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The *k* values are reflected in inflexion time [(ln3*B*)/*k*]. Murrah females precociously reached the inflexion point at 155 days, while male Jaffarabadi took approximately 3 extra months to reach the same point (Table 3). Mediterranean animals (both sexes), female Jaffarabadi and male Murrah individuals reached the inflexion point (age and weight) at the same time. The exception was weight of female Jaffarabadi, who were approximately 20 kg plus light at the inflexion point.

Brody (1945) established in cattle the growth curve as sigmoid with two distinct phases. First, growth accelerates until puberty, predominantly adding bone and muscle tissue stimulated by the release of growth hormone. In the second phase, after puberty, growth is slowed due to action of steroid hormones that increase the deposition of adipose tissue (Grant and Helferich, 1991).

Degree of maturity at different ages (Table 4) corroborates the inflection point results, with male Jaffarabadi showing a lower degree of maturity - reaching 50% (*A*50%) and 75% (*A*75%) of the mature weight at 13.4 and 22.4 months, respectively. Mediterranean animals (that are bred for meat production) achieved *A*75% at about 20 months of age. The highest average maturity weight and lower precocity of Jaffarabadi buffaloes is related to biotype. Usually, animals with a larger body form also have higher energy requirements.

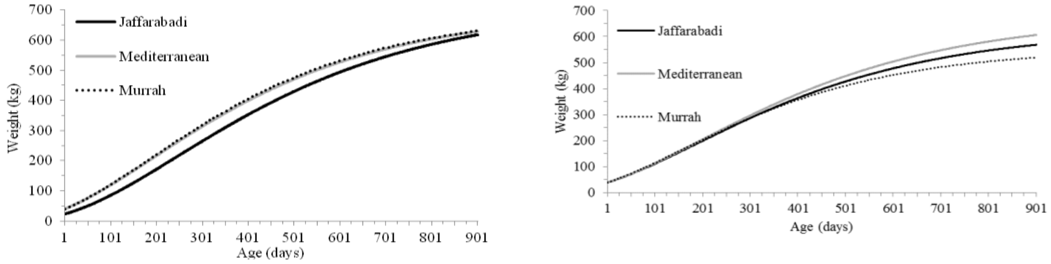
Agudelo-Gómez et al. (2009) analyzed near 2,000 buffaloes from Colombia in three production systems, reporting average values for *A*50% of 367 to 1,098 days for males and 354 to 839 days for females. For *A*75%, the same authors reported averages ranging from 712 to 2280 (males) and 700 to 836 days (females). When compared to the buffalo in Colombia the results for our study are quite satisfactory, since all breeds reached 75% of their mature weight before two years.

The growth curves of male Murrah and male Mediterranean were very similar (Figure 1), a consequence of the small difference in *A* and *k* parameters (Table 3). Jafarabadi growth was slower, reaching the mature weight of the other two breeds at approximately 30 months of age. It should be noted that the Absolute Growth Rates (AGRs) of male Jaffarabadi from the second year of life is superior to all other breeds (Figure 2). *AGR* values for males reached a maximum value of 0.940, 0.990 and 1.015 kg for Jaffarabadi, Mediterranean and Murrah, respectively. Murrah males had the highest gain among all groups (breed and sex) up to 10 months of age. This result provides support for the use of male calves for meat production in dairy cattle of this breed.

Female growth in the three breeds was similar until near 10 months of age (Figure 1). After this age, Mediterranean females had higher weight gain. The maximum *AGRs* were 900, 940 and 897 grams for Jaffarabadi, Mediterranean and Murrah,

Table 4. Degree of maturity (%) at different ages by sex for Jaffarabadi (JAF), Mediterranean (MED) and Murrah (MUR) using Von Bertalanffy model.

Age (Days)	Male			Female		
	JAF	MED	MUR	JAF	MED	MUR
100	11.7	16.9	17.2	17.4	16.4	20.4
205	24.6	31.8	32.4	32.3	30.8	37.3
365	45.2	53.3	54.7	53.9	51.9	60.2
550	64.6	71.7	72.6	72.0	70.2	77.7
730	77.9	83.4	84.2	83.6	82.2	88.0
Maturity						
*A*50% (days)	408	339	332	337	351	290
*A*75% (days)	684	592	580	588	611	514



(a) (b)

Figure 1. Growth curve for males (a) and females (b) of the Jaffarabadi, Mediterranean and Murrah breeds using Bertalanffy fuctions.

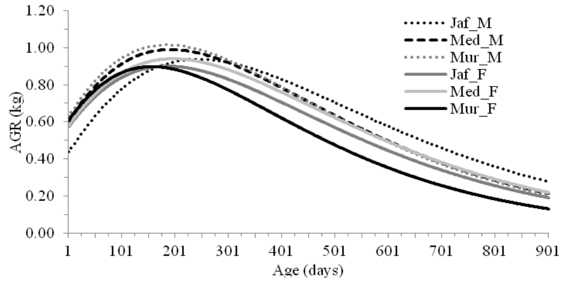


Figure 2. The Absolute Growth Rate (AGR) for Males (M) and Females (F) of Jaffarabadi (Jaf), Mediterranean (Med) and Murrah (Muh) breeds using Bertalanffy functions.

respectively.

Pearson correlations between *A* and *k* were negative and significant (P< 0.01), with a high association recorded for the Mediterranean breed (-0.70) and low association for the Jaffarabadi breed (-0.33) (Table 5). These results indicate that animals with lower growth rates (particularly within the Mediterranean breed) are more likely to reach higher weight values as adults. Indeed, a negative genetic correlation between both parameters has previously been observed in buffaloes (Agudelo-Gómez *et al.*, 2009). Pearson correlations between *A* and weights at different ages were moderate to high in the Jaffarabadi breed, and negative and low between *A* and W205/W365 for the Murrah breed (Table 5).

The first and the second principal components explained 71.4 and 23.3%, of the variation between breeds, respectively (Figure 3). The variables that most contribute to the first component ($\hat{y}$= 0.51*A*-0.37*K*+0.19 W205+0.52 W365+0.53 W550) were weights between weaning and maturity. The most important parameters were weight at maturity (A) and Weights at 365 (W365) and 550 days (W550). The second component ($\hat{y}$= -0.17+ 0.59K+0.75 W205+0.15 W365+0.15 W550) had the highest scores for growth rate (k) and Weight at 205 days of age (W205).

Murrah females are distinguished by their high precocity and small size from weaning until maturity. Animals with higher precocity are more efficient in reproduction, reducing the generation interval, increasing genetic progress and allowing producers to optimize their production systems to ensure faster financial returns.

One potential option to produce males for slaughter with higher body form without compromising (or even increasing) milk production is through crossbreeding Murrah females with Mediterranean males. There is some evidence that this is feasible: Dias *et al.* (2010) reported higher milk production in Murrah×Mediterranean crosses as compared to Murrah pure animals

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Table 5. Pearson correlations between curve parameters (A and k) and Weights at 205 (W205), 365 (W365) and 550 (W550) days of age.[a]

Pearson correlation	Breed		
	Jaffarabadi	Mediterranean	Murrah
A and *k*	-0.33^{**}	-0.70^{***}	-0.63^{***}
A and W205	0.58^{***}	0.20^{***}	-0.11^{*}
A and W365	0.70^{***}	0.34^{***}	-0.17^{**}
A and W550	0.82^{***}	0.72^{***}	0.31^{**}
k and W205	0.11^{ns}	0.30^{***}	0.33^{***}
k and W365	0.17^{ns}	0.19^{***}	0.56^{***}
k and W550	-0.02^{ns}	-0.30^{***}	0.013^{ns}

[a] ns= Not significant; * $P< 0.05$; ** $P< 0.01$, *** $P< 0.001$.

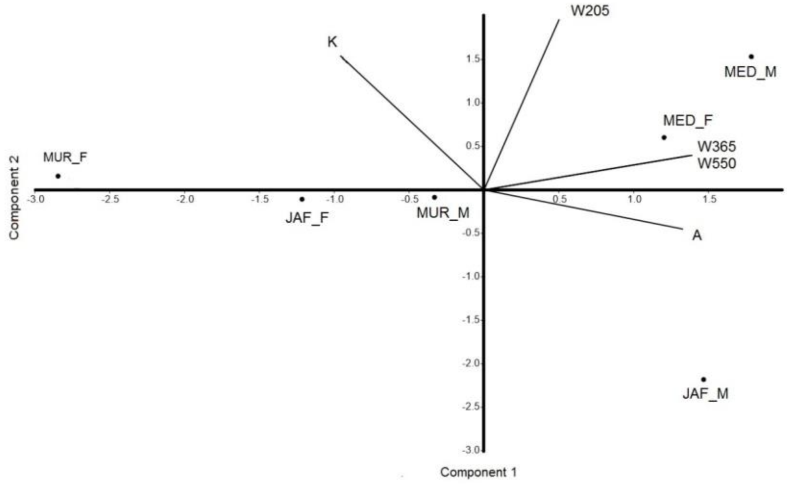

Figure 3. Biplot by Principal Component Analysis (PCA) for Males (M) and FFemales (F) of Jaffarabadi (JAF), Mediterranean (MED) and Murrah (MUR) breeds.

Jaffarabadi males have high gain post-weaning weight and high adult weight, with lower precocity. In contrast, Jaffarabadi females are intermediate in adult size and precocity. Therefore, when compared to Murrah and Mediterranean breeds, these animals mature late and grow large, and therefore have the greatest need for resources. However, the birth weight of Jaffarabadi was the lowest of the three breeds (Table 1). Thus, one strategy would be to use Jaffarabadi as a paternal breed in crossbreeding, with the purpose of exploiting heterosis without causing problems in calving due to its larger size. Additionally, the Jafarabadi breed may be used in crossbreeding with other breeds, when there is need to increase the body form of the herd.

Compared with *Bos indicus* or *Bos Taurus*, buffaloes grow faster and therefore reach slaughter weight more rapidly (Angulo *et al.,* 2006). They also have a better rate of feed conversion (Vale *et al.,* 2013). Buffalo also has high levels of acceptance in the meat market; consumers gave higher hedonic scores for buffalo meat products (Spanghero *et al.,* 2004). These results emphasize the potential importance of buffaloes for meat production in Brazil. A further advantage is that buffaloes are often farmed in regions where the bovines do not have good adaptability.

CONCLUSIONS

Murrah breed females have high precocity and low weight at maturity; an important biotype for milk production. Murrah males have intermediate values, indicating a high potential for meat production in dairy herds. Mediterranean breed buffaloes are characterized by high weight gain, median precocity and medium to high weight at maturity, confirming its principal role in beef production in Brazil.

Jaffarabadi breed males have high weight at maturity and slow growth in the first year of life, and high growth from this time until maturity. Female Jaffarabadi are smaller and have precocity similar to Mediterranean animals. Male Jaffarabadi may be excellent candidates for crossbreeding with Murrah and Mediterranean breeds if the goal is to increase the body form of the herd.

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مقایسه مدل های غیر خطی برای توصیف منحنی های رشد بوفالوهای Murrah و Mediterranean ،Jaffarabaddi

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چکیده

شناخت منحنی های رشد بوفالو برای بهبود مدیریت باروری، استراتژی های تغذیه ای و شناسایی بهترین سن کشتار ضروری است. ما اولین مطالعه مشترک مقایسه منحنی های رشد سه نژاد بزرگ بوفالو را ارائه می دهیم. علاوه بر این، از تجزیه و تحلیل مولفه های اصلی و گرافیک بیوپلت برای ارزیابی میزان تشابه بین گروه ها (نژاد با جنس) و ارتباط آنها با وزن بالغ، میزان بلوغ و وزن در سنین مختلف استفاده شد. این مجموعه شامل ۸۵۰۵۰ رکورد وزن از ۱۳۹۱ Jaffarabaddi ، Mediterranean و Murrahبود. مدل Bertalanffy به بهترین شکل مناسب بود. وزن بالغ برای نر و ماده Mediterranean به ترتیب ۵۰/۸ ± ۶۹۶/۶ کیلوگرم و ۹/۶۷ ± ۶۷/۴۳ کیلوگرم ، برای

Murrah کیلوگرم و برای ۶۲۹ ± ۶۰/۳۲ کیلوگرم و ۱۶۶/۴۸ ± ۴۶/۴۸ کیلوگرم Jaffarabaddi ۶۹/۶۹۴ و ۱۵.۴۹± ۵۵۶.۵۳ کیلوگرم بود که توسط مدل Bertalanffy بدست آمد. تمام نژادها در کمتر از دو سال به ۷۵٪ بلوغ رسیدند. ماده های Murrah، بیشتر تولیدی بودند و دارای زودرسی بالا و وزن بالغ کم بودند (بیوتیپ های مهم برای تولید شیر) . نران Murrah خصوصیات متوسطی را نشان دادند و پتانسیل بالایی برای تولید گوشت در گله های شیری نشان دادند. نوع مدیترانه ای وزن بالا، زودرسی و وزن بالغ متوسط دارد که ازدلایلی است که باعث می شود این نژاد، گوشت اصلی در برزیل باشد. نرهای Jaffarabaddi، وزن بالغ بالایی دارند، رشد آهسته در سال اول زندگی و پس از آن رشد بالایی دارند. ماده های Jaffarabadi کوچکتر بودند و از نظر سطح زودرسی شبیه نوع مدیترانه ای بودند. بوفالوها در برزیل به طور سنتی برای تولید شیر استفاده می شوند؛ با این وجود، مطالعه ما به وضوح نشان می دهد که هر سه نژاد ویژگی های مناسب برای تولید گوشت دارند.

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