Regression Equations for Estimating the Weight of Taiwanese Buffaloes from Size Characteristics(1)

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Research Article

Keywords: Taiwan water buffalo, Growth rate, Growth traits, Parity effect

Posted Date: February 3rd, 2022

DOI: <https://doi.org/10.21203/rs.3.rs-1289866/v1>

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Abstract

We investigated the growth rate and appearance traits of a herd of 83 buffaloes in Eastern Taiwan. Parity, body weight and length, withers height, and chest girth (from birth to > 5 years of age) were recorded. The results indicated the mean male buffalo body weights at birth and at 6, 9, 12, and 24 months old were 38.2 ± 5.3 , 102.2 ± 16.0 , 143.7 ± 24.1 , 176.5 ± 28.4 , 194.6 ± 34.1 , and 323.3 ± 69.0 kg, respectively. The mean female buffalo body weights at birth and at 6, 9, 12 and 24 months old were 37.8 ± 5.8 , 90.6 ± 17.2 , 137.9 ± 21.9 , 155.9 ± 25.3 , 171.1 ± 28.2 , and 311.4 ± 53.0 kg, respectively. Male buffaloes were significantly heavier than their female counterparts at 3, 9 and 12 months old ($P < 0.05$). The fitted regression equations for body weight with respect to chest girth from birth to 6 months old and from 6 to 24 months old, respectively, were (1) weight = $2.04 \times$ chest girth – 124.19 and (2) weight = $4.19 \times$ chest girth – 387.80. The respective R^2 values were as high as 0.93, and all P values were significant ($P < 0.0001$), indicating that these regression equations are useful for estimating the weight of Taiwanese buffaloes in the absence of a scale. Additionally, the mean birth weight for buffalo calves from primiparous buffalo cows was significantly lower than that for parous buffalo cows (32.1 vs. 40.3 kg, $P < 0.0001$).

Introduction

Water buffaloes (*Bubalus bubalis*) are crucial to the economies of developing countries, especially in rice-growing regions such as southern China or the Indian subcontinent. Buffaloes not only provide agricultural labor but also provide buffalo milk and meat (Nanda and Nakao, 2003; Michelizzi et al., 2010). Statistics from FAO 2019 reported that the current buffalo population is approximately 231 million worldwide, which is the fifth largest livestock population globally (FAOSTAT, 2019). Evidence indicates that buffaloes are present in 129 countries (Misra and Tyagi, 2007). Buffaloes can be classified into river buffaloes and swamp buffaloes according to their phenotype, behavior, and karyotype. River buffaloes, used mainly for dairy production, have 25 pairs of chromosomes and are mainly found in Africa, Eastern Europe, the Middle East, and India. The population of river buffaloes in India is nearly 98 million and accounts for about 70% of the world's buffalo milk production. Swamp buffaloes, by contrast, have 24 pairs of chromosomes; are found mainly in China, northeastern India, Bangladesh, and Southeast Asia; and are used primarily for the purpose of labor (Cockrill, 1981; Kumar et al., 2007; Zhang et al., 2015).

Buffaloes have a wide geographical range, are highly environmentally adaptable, and are disease resistant. Compared with that of dairy cows, the rumen of buffalo develops earlier and more rapidly, resulting in a greater presence of rumen microorganisms than that found in cattle breeds. Buffaloes are more efficient at digesting fiber, rumen feed, and agricultural and sideline byproducts than are other breeds of cattle; therefore, production cost for milk or meat is relatively low for the buffalo (Guyton, 1991; Ermetin, 2017). Additionally, the nutritional composition of buffalo meat is low in fat, calories, and cholesterol. Buffalo meat's high iron content and high ratio of polyunsaturated fatty acid enable it to be part of a healthy, modern diet (Borghese and Manzi, 2005; Rocha, 2001; Ermetin, 2017). An Italian study reported that the average annual beef consumption per person in Italy has gradually decreased from 24.9

kg in 2007 to 17.1 kg in 2017 (Tamburrano et al., 2019), and buffalo meat is gradually replacing beef in the Italian diet. Market standards require that the quality of buffalo carcasses must have a net slaughter rate of at least 57% and must contain at least 62% lean content and less than 3% fat content. Additionally, buffalo meat should be tender and juicy, should have a cholesterol content <50 mg/100 g, an unsaturated to saturated fatty-acid ratio >1, and an iron content >1.5 mg/100 g, among other requirements (Borghese, 2010).

Taiwan's buffalo population comprises swamp buffaloes and was introduced to Taiwan for farming in the 16th century from Guangdong and Fujian provinces. After the introduction of the swamp buffalo to Taiwan, the buffalo population grew rapidly, reaching a peak of 320,000 buffaloes in 1960. With the mechanization of agriculture, fewer economic incentives for raising buffaloes (compared with other preferred cattle species), and a lack of buffalo-based cuisine in Taiwan, the country's buffalo population (currently, $\approx$ 2000 heads) has been decreasing. Because of the rapidity of the decline of the Taiwanese water buffalo population, preserving this precious livestock resource is vital. As part of such an effort, this study aimed to examine the birth weights, body lengths, withers heights, and chest girths of 49 calves born on a buffalo breeding farm in eastern Taiwan from 2016 to 2018 and to compare the data with those of 34 mature buffaloes from survey reports from an international journal.

Material And Methods

Tested animals and breeding model

The studied buffaloes were from two herds. The first herd comprised 21 male and 28 female buffaloes that were born at any time from 2016 to 2018. The second herd comprised one mature bull and 33 mature cows, all more than 5 years old. After birth, the water buffaloes were raised in a pen by their mother and were provided daily with 4 kg of commercial feeding concentrate that had 16% of protein and 2580 kcal/kg of metabolizable energy. Additionally, chopped hay, drinking water, and mineral salts were provided ad libitum for both buffalo cows and their calves. Upon reaching 1 month of age, calves were transferred to the creep feeding area with their mother, and the calves were provided with additional commercial feeding concentrate in an amount equivalent to 1% of the calves' body weight. When weaning began at the age of six months, the calves were moved to a semiopen barn, and 1 kg of commercial feeding concentrate and the equivalent of 3% of the calves' body weight in hay were provided daily until the calves reached 12 months of age. At the age of 12 months, male and female buffaloes were grouped in fields for grazing. In winter, they were provided with hay ad libitum, and the use of commercial concentrates was discontinued at this stage.

Collection Of Data On Phenotypic Traits

Parity, body weight, body length, withers height, and chest girth of the tested buffaloes were recorded at birth and at 3, 6, 9, 12, and 24 months of age. Average daily weight gain was calculated and recorded,

and the weights of the mature buffaloes >5 years old were also recorded.

Statistical analysis

The experimental data were analyzed using analysis of variance with a general linear model in SAS (Version 9.2, SAS Institute, 2009) statistical software, and the least mean squares method was used to determine significant differences.

Results And Discussion

Body weight and growth rate

The two Taiwan buffalo herds in the study were transported monthly to an automatic weighing station for calculating their gain (expressed in mean weight gain over an average day of that month) and weight. The growth data are presented in Table 1. The male and female buffaloes' mean birth weights were 38.2 ± 5.3 and 37.8 ± 5.8 kg, respectively. Asian buffaloes have a mean birth weight of 35–40 kg. The mean birth weights for buffaloes on a farm in Hualien, Taiwan, reported by Wei et al. (2011) 10 years before this study were 34.6 ± 4.2 and 29.9 ± 3.8 kg for male and female buffaloes, respectively. Mean birth weight has since increased by 4 to 8 kg, indicating the effectiveness of selection occurring on this farm. The 6-month-old mean weaning weights were 143.7 ± 24.1 and 137.9 ± 21.9 kg for male and female buffaloes, respectively; these figures are similar to the surveyed data from the previous measurements taken 10 years before (145 ± 25.4 kg for male water buffaloes and 132 ± 25.3 kg for female water buffaloes) (Wei et al., 2011). The mean daily weight gain indicated that the most rapid growth rate observed for buffaloes in the present study was that from birth to 3 months of age, with a mean daily weight gain ranging from 0.57 to 0.63 kg/day.

Table 1
Body weight and mean daily weight gain of Taiwan water buffaloes at different ages, in months

Items ¹	Male (n=21)			Female (n=28)		
BW0, kg	38.2	±	5.3	37.8	±	5.8
BW3, kg	102.2	±	16.0 ^a	90.6	±	17.2 ^b
BW6, kg	143.7	±	24.1	137.9	±	21.9
BW9, kg	176.5	±	28.4 ^a	155.9	±	25.3 ^b
BW12, kg	194.6	±	34.1 ^a	171.1	±	28.2 ^b
BW24, kg	323.3	±	69.0	311.4	±	53.0
Adult (over 60 months of age), kg	784		(n=1)	538.8	±	70.8 (n=33)
ADG0~3, kg/day	0.63	±	0.12	0.57	±	0.12
ADG3~6, kg/day	0.45	±	0.23	0.51	±	0.20
ADG6~9, kg/day	0.32	±	0.19 ^a	0.20	±	0.17 ^b
ADG9~12, kg/day	0.18	±	0.19	0.14	±	0.18
ADG12~24, kg/day	0.33	±	0.12	0.38	±	0.13
Values are in terms of means ± standard deviation for the given trait						
^{a, b} Means within the same row with different superscripts differ significantly ($P < 0.05$)						
¹ BW0, BW3, BW6, BW9, BW12, and BW24 represent the body weight at birth and at 3, 6, 9, 12, and 24 months of age; ADG0–3, ADG3–6, ADG6–9, ADG9–12, and ADG12–24 represent the mean daily weight gain from birth to 3 months of age and at 3–6, 6–9, 9–12 and 12–24 months of age						

The comparison of the weight of male water buffaloes with that of female water buffaloes indicated that the body weight of bulls at ages 3, 9 and 12 months was significantly higher than that of cows ($P < 0.05$). The results for the mean daily weight gain revealed a significantly more rapid growth rate for male water buffaloes between 6 and 9 months than for that of female water buffaloes during the same growth stage ($P < 0.05$); no significant difference was observed in the other stages.

The second group comprised a single, mature male buffalo 7 years of age with a body weight of 784 kg and 33 mature female buffaloes over 5 years of age with a mean body weight of 538.8 ± 70.8 kg; these values are both similar to the previous survey data from 10 years before, when the mean body weight for female buffaloes was 512 ± 24.3 kg) (Wei et al., 2011).

Soysal (2013) reported in a survey that the mean birth weight of male and female Turkish water buffaloes were 26.7–34.3 and 22.1–31.6 kg, respectively; the mature body weight was reported to be

411.0–518.6 kg on average. Chen et al. (2016) investigated the weight of 76 growing milk buffaloes on an 11–14-month-old buffalo farm attached to the Buffalo Research Institute of the Chinese Academy of Agricultural Sciences and reported a mean weight of 245.01 ± 33.92 kg. Yu et al. (2018) investigated the growth performance of Binglangjiang water buffaloes and observed the following mean weights: 34.35 ± 4.58 and 32.84 ± 4.27 kg for newborn bulls and cows, respectively; 86.7 ± 9.67 and 80.7 ± 9.86 kg for 3-month-old bulls and female calves, respectively; 129.8 ± 13.8 and 123.2 ± 13.4 kg for 6-month-old bulls and cows, respectively; 228.3 ± 21.9 and 214.9 ± 25.4 kg for 12-month-old bulls and cows, respectively; 483.9 ± 17.9 and 399 ± 20.4 kg for 24-month-old bulls and cows, respectively; and 659.5 ± 15.9 and 502.9 ± 68.9 kg for mature bulls and cows, respectively. In a survey report, de Araujo Neto et al. (2019) observed that the mean weights of Brazilian buffaloes at 100, 365, and 550 days were 82.95 ± 16.15 (n = 2006), 212.45 ± 45.15 (n = 959), and 292.79 ± 67.97 kg (n = 847), respectively.

Relative to the weights reported in the literature, the weights measured in this study were heavier, lower, and slightly higher for the periods of birth to 6 months of age (specifically, weaning weight); of 1 to 2 years of age, and from maturity onward, respectively.

Growth Performance

The mean withers height, body length, and chest girth of Taiwanese male buffaloes at birth. were 71.0 ± 3.8 , 60.2 ± 5.2 , and 78.3 ± 5.5 cm, respectively. For female water buffaloes at birth, the mean figures were 72.9 ± 5.2 cm for withers height, 62.5 ± 4.8 cm for body length, and 80.2 ± 5.0 cm for chest girth. No significant differences between male and female buffaloes were observed for any of the measurements. The mean withers height, body length, and chest girth of mature female water buffaloes over 5 years old were 140.9 ± 6.8 , 122.4 ± 4.2 and 202.2 ± 7.0 cm, respectively (Table 2). In the findings of Wei et al. (2011), the birth withers height, body length, and chest girth of the male buffaloes in the Hualien farm were 71.5 ± 2.0 , 45.6 ± 5.7 , and 79.9 ± 5.9 cm, respectively, and those of female buffaloes at birth were 69.5 ± 3.9 , 49.3 ± 6.5 , and 74.1 ± 3.5 cm, respectively. The mean length of male and female water buffaloes in this study were significantly greater, and the withers heights and chest girths of female water buffaloes were greater than the buffaloes 10 years ago. The data indicate that after 10 years of selection from birth, the buffaloes had slightly larger body sizes.

Table 2

Body conformation measurements of Taiwan water buffaloes at different ages, in months

Items	Months of age	Male (n=21)			Female (n=28)		
Withers height, cm	0	71.0	±	3.8	72.9	±	5.2
	3	90.0	±	4.0	89.3	±	6.8
	6	95.1	±	5.0	94.3	±	4.6
	9	100.3	±	5.1 ^a	96.3	±	4.1 ^b
	12	102.0	±	4.1	99.7	±	4.0
	24	115.0	±	6.4	113.1	±	4.1
	Over 60	160.0		(n=1)	140.9	±	6.8 (n=33)
Body length, cm	0	60.2	±	5.2	62.5	±	4.8
	3	81.7	±	5.3	82.2	±	6.8
	6	90.6	±	6.8	90.1	±	7.4
	9	100.3	±	5.9 ^a	96.0	±	6.8 ^b
	12	103.0	±	7.5	99.8	±	6.1
	24	119.9	±	9.6	118.3	±	7.7
	Over 60	137.0		(n=1)	122.4	±	4.2 (n=33)
Chest girth, cm	0	78.3	±	5.5	80.2	±	5.0
	3	116.0	±	8.7	115.2	±	8.3
	6	128.5	±	7.3	127.4	±	6.3
	9	136.4	±	8.8 ^a	130.8	±	8.1 ^b
	12	142.0	±	9.2 ^a	134.0	±	8.0 ^b
	24	164.9	±	13.1	165.1	±	8.1
	Over 60	226.0		(n=1)	202.2	±	7.0 (n=33)
Values are in terms of means ± standard deviation for the given trait							
ⁿ Sample size							
^{a, b} Means within the same row with different superscripts differ significantly ($P < 0.05$)							

In our Pearson correlation coefficient analysis, the correlation coefficients between withers height and birth weight, between body length and birth weight, and between chest girth and birth weight were 0.9203,

0.9389, and 0.9423, respectively. The correlation coefficients between chest girth and withers height, and between withers height and body length were 0.9461 and 0.9544, respectively; and the correlation coefficient between body length and chest girth was 0.9530. All these correlations were significant at $p < 0.0001$, indicating that these four physical characteristics were all highly correlated (Table 3).

Table 3
Pearson r correlation matrix analysis

Items	Body weight	Withers height	Body length	Chest girth
Body weight	1			
Withers height	0.9203 ^{***}	1		
Body length	0.9389 ^{***}	0.9461 ^{***}	1	
Chest girth	0.9423 ^{***}	0.9544 ^{***}	0.9530 ^{***}	1
^{***} Correlation is significant at the 0.0001 level				

Wei et al. (2011) reported that the mature withers height, body length, and chest girth of male water buffaloes were 130 ± 6.6 , 143 ± 10.6 , and 208 ± 12.4 cm respectively; the mature withers height, body length and chest girth of female water buffaloes were 127 ± 3.9 , 137 ± 9.1 , and 205 ± 7.3 cm, respectively. Soysal (2013) reported that the mature withers height, body length, and chest girth of Turkish male buffaloes were 138.23, 145.09, and 222.77 cm, respective; the mature withers height, body length, and chest girth of Turkish female buffaloes were 133.14, 142.43, and 196.59 cm, respectively. Chen et al. (2016) surveyed 76 milk buffaloes affiliated with the Buffalo Research Institute of the Chinese Academy of Agricultural Sciences. The mean withers height of the growing milk buffaloes from 11 to 14 months was 109.24 ± 4.95 cm, the mean body length was 109.25 ± 8.56 cm, and the mean chest girth was 158.13 ± 9.45 cm. The correlation coefficients between the three physical parameters and body weight were 0.676, 0.773, and 0.823, respectively, and significant at $P < 0.01$. Overall, the buffaloes examined in this study tended to have a long vertical height but short front-to-back length.

Growth Curve

A total of 49 buffaloes had their measurements taken. The growth period was divided into two stages by weaning at the age of 6 months. The collected chest girth data and the weight data were subjected to linear regression analysis (Fig. 1), and the fitted equations were $\text{Weight} = 2.04 \times \text{Chest girth} - 124.19$ for the period of birth to 6 months of age and $\text{Weight} = 4.19 \times \text{Chest girth} - 387.80$ for the period of 6–24 months of age; the R^2 values of these two equations reached 0.93, and each factor's P value ($P < 0.0001$) indicated that the extreme regression equations have practical value and that body weight can be estimated by measuring only the chest girth value, which is relatively easy to do.

Chen et al. (2016) formulated multiplied regression models with the factors of withers height, body length, back height, chest girth, loin girth, chest width, chest depth, rump length, rump width, and cannon circumference of the water buffaloes. Ten equations with correlation coefficients between 0.72 and 0.83 were obtained. The equations were closely fitted to the estimated body weight of buffaloes. In general, chest girth can be used to precisely estimate the weight of water buffaloes in the absence of data on other parameters, and farmers in rural areas should be encouraged to do so because chest girth is easy to measure.

Parity

Results on the effect of parity on the growth performance of the tested buffaloes revealed that primiparous factors substantially influenced the birth weight of the calves. The mean calf birth weight of the primiparous cows was 31.2 kg, which was significantly lower than that of the multiparous cows (2–6 litters; 40.3 kg; $P < 0.0001$). Primiparous factors also had a significant influence on the growth performance of the calf at the age of 3 months. The mean calf weight of the primiparous cows at 3 months was 80.4 kg, which was significantly lower than the mean calf birth weight of the multiparous cows (99.4 kg, $P < 0.01$). Parity exerted no significant effect on body weight at 6, 9, 12, and 24 months (Fig. 2). These results indicate that the benefit of mothers in parity is crucial for the growth of calves before weaning but for follow-up, reliable feeding management and feeding strategies should be considered.

Declarations

The care and use of animals in this study was approved by the Hualien Farm Laboratory Animal Management Committee.

Acknowledgments

All the authors would like to acknowledge Incharge and staff members of Hualien Animal Propagation Station, COA-TLRI for continuous support and facilitation regarding the collection of data.

This manuscript was edited by Wallace Academic Editing.

Funding The research work was accomplished in the institute research program of Hualien Animal Propagation Station funded by COA-TLRI.

Competing interests The authors declare no competing interests.

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Data availability Data will be made available from the corresponding author on reasonable request

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Figures

Figure 1

Regression between body weight and chest circumference for Taiwan water buffaloes. Left: from birth to 6 months old; Right: from 6 to 24 months old

Figure 2

Effect of parity on body weight (mean $\pm$ SE) of Taiwan water buffaloes at different ages, in months