Agr. Nat. Resour. 57 (2023) 677–688

AGRICULTURE AND NATURAL RESOURCES

Journal homepage: http://anres.kasetsart.org

Research article

Effects of Brahman genetic resource proportion on growth performance traits of beef crossbreds in Western Highlands of Vietnam

Pham Van Gioi[a,*], Dang Van Dung[a,†], Pham Van Son[a,†], Dao Van Lap[b,†], Pham Van Tiem[c,†]

[a] Animal Genetics and Breeding Department, National Institute of Animal Science, Hanoi 11913, Vietnam

[b] Vietnam Ruminant Breeding Centre, National Institute of Animal Science, Hanoi 11654, Vietnam

[c] Department of Science and Technology for Economic Technical Branches, Ministry of Science and Technology, Hanoi 11313, Vietnam

Article Info

Article history:
Received 24 April 2023
Revised 14 June 2023
Accepted 18 July 2023
Available online 31 August 2023

Keywords:
Average daily gain,
Beef cattle,
Body weight,
Brahman cattle,
Growth performance

Abstract

Importance of the work: Of the many studies on beef cattle in the Western Highlands of Vietnam, none have reported on the genetic resources of the Brahman breed.

Objectives: To evaluate the impact of the Brahman breed on the growth performance of beef crossbreds.

Materials & Methods: During 2017–2020, data were collected from 1,069 calves in 243 households, consisting of body weight (BW) and the average daily gain (ADG) from birth to age 24 mth. The data were analyzed using the Proc GLM linear regression approach in the SAS 9.0 software, with fixed effects of location, calving year, calf sex and breed group.

Results: Upgraded crossbreds with a proportion of Brahman breed genetics could be developed successfully in the Western Highlands, with the upgraded cattle having linearly increased growth and groups containing 75% or more Brahman breed producing faster growth, with ADG values from birth to age 24 mth of 527.32–561.01 g/d. Based on Local Yellow cattle, for every 1% increase in the Brahman breed in the crossbreds, the BW increased from 0.14 kg at birth to 2.43 kg at 24 mth, with an ADG increase from 1.42g/d to 4.47g/d. Based on Red Sindhi crossbreds, for every 1% increase of Brahman breed genetic resource, the BW increased from 0.17 kg at birth to 2.30 kg at 24 mth, with an ADG increase from 1.72g/d to 3.98g/d.

Main finding: The Brahman breed had a positive effect on growth performance in crossbreds. The higher genetic proportion of Brahman in the crossbreds, the better the growth performance they acquired. Upgrading using the Brahman breed to improve growth performance would be an appropriate and favorable solution for the beef industry in the Western Highlands of Vietnam.

† Equal contribution.

* Corresponding author.
E-mail address: Gioikhiet@yahoo.com.vn (P.V. Gioi)

https://doi.org/10.34044/j.anres.2023.57.4.12

Introduction

The Western Highlands, as well as many other mountainous and alpine zones in Vietnam, are represented by vast areas, sparse population densities, extensive natural grasslands, plentifully and agricultural byproduct resources that are well used for ruminants (Hai et al., 2009; Giang, 2017; Hue, 2020; Tai, 2021). In addition, many ethnic minority groups practice very good traditional customs and experience in their cattle husbandry, involving their ancient culture associated with cattle production in festivals, at weddings and in other collective worshiping activities (Hai et al., 2009; Huy, 2017; Huong and Trong, 2021; Huong, 2023). The actual climactic conditions in the Western Highlands can appear to be harsh, with drought and extreme weather events and associated characteristic soil conditions (Phuong and Nguyet, 2015, Department of Water Resources Management, 2019). In the past, climatic variation has resulted in heavy losses from droughts; thus, new beef breeds introduced into this region need to be able to overcome all these restrictions. In the past, this region has benefitted substantially from the Government's Red Sindhi program, resulting in a large number of Red Sindhi crossbreds (RSCs), with ethnic minority communities raising Local Yellow (indigenous) cattle (LYC) herds. In Vietnam, several scientists have investigated the beef crossbreds in this region; however, they did not investigate in detail the influence of the proportion of different genetic resource (La et al., 2017; Quyen et al., 2018; Hai et al., 2019; Linh et al., 2020; Quyen, 2021).

Brahman cattle have an attractive appearance, a red coat and skin color and nice, high withers, with a large dewlap, in accordance with farmers' trend in rural areas. This cattle breed has a greater body weight (BW) than the breed or LYC and RSC, with higher carcass performance, effective feed conversion and high economic efficiency. In addition, Brahman cattle are gentle, docile and highly tolerant of hot and humid conditions, with good resistance to internal and external parasites and good reproductive performance in tropical and subtropical environments (Koger, 1963; Moran, 1970; Finch, 1985; Hohenboken, 1987; Rechav et al., 1990; Hammond and Olson, 1994; Hammond et al., 1996; Alvarez et al., 2000; Hansen, 2004; Svotwa et al., 2007; Schutt et al., 2009; Riley et al., 2012; Collier and Gebremedhin 2015; Cassidy, 2015; Dikmen et al., 2018; Davila et al., 2019; Mateescu et al., 2020; Ahammed et al., 2020; Mateescu et al., 2020).

Many researchers have reported that integrating Brahman cattle in crossbreeding programs has resulted in good performance, with the crossbreds having good growth, mothering ability and resistance to external environmental conditions (Riley et al., 2012; Mateescu et al., 2020). Utilizing the Brahman breed in crossbreeding has produced favorable results, such as hybrid vigor in reproduction, good survival, a high weaning weight, and longer lifespan compared to purebreds (Thrift and Thrift, 2003). Many countries have included Brahman cattle in crossbreeding programs with local cattle that have resulted in considerably improved performance in growth performace, carcass traits as well as adaptation to a hot climate (Waritthitham et al., 2010; Tessema et al., 2013; Kuswati et al., 2014; Papry et al., 2020).

There is a need to determine the appropriate proportion of Brahman breed in crossbreeding to explore the genetic potential of breed groups contributing to crossbreeding combinations. This may clarify the superiority of Brahman cattle: to take advantage of Western Highlands conditions; to utilize effectively the available natural resources; to intensify the use of the social resources of the aboriginal people; and to develop favorable social and economic benefits from beef production, to overcome the obstacles and other negative impacts resulting from drought. Thus, it is necessary to investigate the suitable use of the Brahman breed for crossbreeding for beef production in the Western Highlands, to fulfil both scientific and actual requirements.

Materials and Methods

Materials and durations

In total, 1,069 calves (561 females and 508 males) were studied from nine breed groups (LYC, RSC and crossbreeding combinations with various grades of Brahman breed) from 243 owners in Dak-Lak (547 calves) and Gia-Lai (522 calves) provinces, based on growth from birth to age 24 mth, during 2017–2020 (Table 1).

Methods

Determinations of breeds and breed groups

The LYC and RSC samples were determined based on appearance traits and information supplied from owners, cattlemen, and data or records from local technicians and artificial inseminators. The crossbred groups were determined based on their pedigrees. The breed groups of the calves are detailed in Table 2.

Table 1 Calf group structure for data collection

Breed group	Dak-Lak province	Gia-Lai province	Total
25BrLYC (1/4Br.3/4LYC)	13	23	36
25BrRSC (1/4Br.3/4RSC)	27	7	34
50BrLYC (1/2Br.1/2LYC)	31	34	65
50BrRSC (1/2Br.1/2RSC)	139	124	263
75BrLYC (3/4Br.1/4LYC)	16	7	23
75BrRSC (3/4Br.1/4RSC)	99	123	222
87.5BrRSC (7/8Br.1/8RSC)	25	95	120
LYC (Local Yellow Cattle)	107	53	160
RSC (Red Sindhi Crossbreds)	90	56	146
Overall	547	522	1,069

LYC = Local Yellow cattle; RSC = Red Sindhi crossbreds; 25BrLYC = crossbreds with 25% Brahman and 75% LYC; 25BrRSC = crossbreds with 25% Brahman breed and 75% RSC; 50BrLYC = crossbreds with 50% Brahman and 50% LYC; 50BrRSC = crossbreds with 50% Brahman breed and 50% RSC; 75BrLYC = crossbreds with 75% Brahman breed and 25% LYC; 75BrRSC = crossbreds with 75% Brahman breed and 25% RSC; 87.5BrRSC = crossbreds with 87.5% Brahman breed and 12.5% RSC.

Table 2 Categorization of calf breed groups based on distribution of Local Yellow cattle (LYC), Red Sindhi crossbreds (RSC) and Brahman breed (Br)

Based on genetic resources of LYC and RSC			Based only on Brahman breed		
Calf group	Sire	Dam	Calf group	Sire	Dam
25BrLYC	1/2Br.1/2LYC	LYC	0Br (0% Br)	RSC, LYC	RSC, LYC
50BrLYC	Br	LYC	25Br (25% Br)	1/2Br.1/2LYC	LYC
75BrLYC	Br	1/2Br.1/2LYC		1/2Br.1/2RSC	RSC
25BrRSC	1/2Br.1/2RSC	RSC	50Br (50% Br)	Br	LYC
50BrRSC	Br	RSC		Br	RSC
75BrRSC	Br	1/2Br.1/2RSC	75Br (75% Br)	Br	1/2Br.1/2LYC
87.5BrRSC	Br	3/4Br.1/4RSC		Br	1/2Br.1/2RSC
LYC	LYC	LYC	87.5Br (87.5% Br)	Br	3/4Br.1/4LYC
RSC	LYC, RSC	RSC, LYC		Br	3/4Br.1/4RSC

Br = Brahman cattle; LYC = Local Yellow cattle; RSC = Red Sindhi crossbred; 25BrLYC = 1/4Br and 3/4LYC; 50BrLYC = 1/2Br and 1/2LYC; 75BrLYC = 3/4Br and 1/4LYC; 25BrRSC = 1/4Br and 3/4RSC; 50BrRSC = 1/2Br and 1/2RSC; 75BrRSC = 3/4Br and 1/4RSC; 87.5BrRSC = 7/8Br and 1/8RSC.

Management

Cattle were managed according to grazing during the day on pastureland, supplemented with concentrate when housed in barns. Each day, the cattle were released to graze at 0800–0900 hours and housed at 1800–1900 hours. Concentrate was fed twice daily before releasing in the morning after housing in the evening (Table 3). Forage or fodder and rice straw were supplemented *ad libitum* when housed after grazing. All ruminants were periodically vaccinated according to local veterinary practice in combination with deworming helminthiasis and external parasite eradication.

Monitoring cattle and data collection

Individual identification: Reproductive cows were individually identified based on characteristic appearance traits, such as coat color, horn type, conformation and ear tag number or tattoos, as well as the individual names used by their owners or relevant staff. Calves were mainly identified according to their mothers; after weaning, they were individually identified using colored paint for marking or using ear tag numbering.

Table 3 Ingredients, nutritional contents and regimes for concentrate

Order	Group	Value
A	Ingredients	Percentage in ration
1	Rice bran	45
2	Corn meal	45
3	Bone meal	9
4	Salt	0.5
5	ADE mixture	0.5
	Total	*100*
B	Nutritional value[1]	
1	Crude Protein (%)	11.75
2	ME (KCal/kg)	2600.00
C	Regime	
1	Calves 0–6 mth (kg/calf/d)	0.3
2	Calves 7–12 mth (kg/calf/d)	0.4
3	Calves over 12 mth (kg/calf/d)	0.5

[1] Estimated according to ingredients and nutritional values in Monograph of National Institute of Animal Science (2001).

Birth weights were determined by weighing, the BWs in subsequent age classes were determined based on standardized technical measurements every 3 mth or 6 mth, with continuous monitoring and observation until age 24 mth. The BW data at the researched age classes were converted and estimated according to the method of International Committee for Animal Recording (2020).

Data analyses

A general linear model was applied using the SAS 9.0 software (SAS. Inc., Cary, NC, USA; 2002) for analysis of the dataset based on Equation 1:

$$Y_{ijklm} = \mu + L_i + BG_j + YC_k + S_l + e_{ijklm} \quad (1)$$

where Y_{ijklm} is the observation (BW and ADG at standardized age classes) of the m^{th} calf, belonging to the l^{th} sex, born in the k^{th} year, in the j^{th} breed group at the i^{th} location (province), μ is the overall mean, L_i is the fixed effects of the i^{th} location (i = 2: Dak-Lak and Gia-Lai provinces), BG_j is the fixed effects of the j^{th} breed group (j = 9: LYC, RSC, various crossbred groups, with j = 5 when analyzed based on calf group according to proportion of Brahman breed: group 0%, 25%, 50%, 75% and 87.5% of Brahman breed), YC_k is the fixed effects of the k^{th} calving year (k=4: 2017, 2018, 2019, 2020), S_l is the fixed effects of the l^{th} sex (l=2: male, female) and e_{ijklm} is the random residual errors, assuming that $N(0, \sigma^2_e)$

The least square mean (LSM) was used to compare among breed groups, with $p < 0.05$ treated as a statistically significant difference.

Increments of BW and ADG were determined for a 1% increase in Brahman breed in the crossbreds based on LYC and RSC dams and a pooled dams group (according to the proportion of Brahman breed). The increments were estimated using the procedure for first order linear regression in SAS 9.0based on Equation 2.

$$Y = a + bx + e \quad (2)$$

where Y is the dependent variable (BW, ADG of various breed groups), a is a constant (basic performance), b is the slope (increment), x is an independent variable (proportion of Brahman breed in breed groups from two dam groups: LYC and RSC and calf groups according to the proportion of Brahman breed) and e is the random residual errors assuming that $N(0,\sigma^2_e)$.

Ethics statement

This study was approved by the Ethics Committee of the Vietnam Animal Welfare Association (Approval no. *2023-01/QĐ-VAWA*).

Results

Body weight and average daily gain of calves by breed groups

Body weight in breed groups in different age classes

The results in Table 4 showed that the lowest birth weight was for LYC, which averaged 11.39 kg/calf, followed by RSC (13.94 kg/calf). In the crossbred groups, an increase in the Brahman genetic proportion increased birth weight, with the heaviest birth weight in the group of 87.5BrRSC, which averaged 27.97 kg/calf. In addition, the results revealed that birth weights of crossbreds born from RSC dams were all significantly higher than for crossbreds born from LYC dams.

The weight at age 3 mth was lowest in LYC (average 37.01 kg/calf), followed by RSC (46.28 kg/calf), which was a significant difference. In the crossbred groups, an increase in the Brahman proportion increased the birth weight in both dam groups of LYC and RSC, with the crossbred groups born from RSC dams having a greater increase than from LYC dams. The group with the highest BW was 87.5BrRSC (average 93.57 kg/calf). At this age, the BW values for breed groups were significantly different.

At age 6 mth, LYC had the lowest BW (average 63.14 kg/calf), which was significantly lower than for RSC (78.99 kg/calf). In the crossbred groups with Brahman cattle, the lowest BW was for 25BrLYC (95.35 kg/calf). At this age, BWs gradually increased with the increase in the genetic proportion of Brahman breed in the crossbreds, from 95.35 kg/calf in 25BrLYC to the maximum in 87.5BrRSC (161.54 kg/calf). As with the previous age class, the BWs of crossbreds based on RSC dams were usually higher than those of the crossbreds based on LYC dams. However, there was no significant difference when the Brahman genetic proportion reached 75% in the crossbreds (146.38 kg/calf in 75BrRSC and 131.45 kg/calf in 75BrLYC).

At age 12 mth, the BW of LYC averaged 109.77 kg/calf, which was the lowest weight in the calf groups. The average BW of RSC calves was 136.21 kg/calf, which was significantly higher than for LYC calves. As with to previous period, the BWs of crossbreds gradually increased with an increase in the Brahman genetic proportion in both groups (LYC and RSC dams). For the same crossbreeding level, the crossbreds based on RSC dams were usually significantly heavier than the crossbreds based on LYC dams. For example, 25BrRSC calves had an average BW of 198.89 kg/calf, with 25BrLYC calves averaging only 162.74 kg/calf. The BW of crossbreds based on RSC dams was highest for 87.5BrRSC (283.46 kg/calf).

At age 18 mth, the average BW of LYC calves was 158.01 kg/calf, which was significantly lower than for the RSC group (194.33 kg/calf). In all crossbred groups, 25BrLYC had the lowest BW (220.05 kg/calf), while the highest was for the 87.5BrRSC group (368.71 kg/calf). As with the previous stage, for the same crossbreeding level with Brahman cattle, the crossbreds based on RSC dams were usually heavier than those based on LYC dams. Specifically, in with 25% Brahman breed, the crossbreds based on LYC dams weighed significantly less (220.05 kg/calf) than for the RSC dams (272.87 kg/calf). However, in with the higher 75% Brahman breed, the crossbreds based on RSC dams (341.31 kg/calf) were heavier than on LYC dams (308.57 kg/calf), but not significantly so.

The BW at age 24 mth for LYC calves reached 181.63 kg/head and for RSC calves averaged 222.23 kg/head, which was significantly higher. Analogous with the previous age classes, upgrading using the Brahman breed in crossbreds resulted in a gradual BW increase for both dam groups. In the LYC dam group, the BW increased from 251.97 kg/head in 25BrLYC to 366.44 kg/calf in the 75BrLYC group. For the RSC dam group, the BW increased from 317.77 kg/calf in 25BrRSC to 432.71 kg/head in the 87.5BrRSC group. At this age, as with the previous period, for the same crossbreeding level of Brahman cattle, the BWs of crossbreds born from LYC dams were always lower than the crossbreds born from RSC dams.

Considering the crossbred groups based on the Brahman genetic proportion and the pooled group of the LYC and RSC dams (Table 5), the BWs of the crossbreds regularly increased with an increase in the Brahman genetic proportion in the crossbreds for all age classes from birth to 24 mth, with the BWs among crossbred groups at the same age always being significantly different. Specifically, at birth, calf groups without an component of Brahman breed, or the pooled group of LYC and RSC calves had BWs of 12.54 kg/calf, which increased in crossbred groups with 25%, 50%, 75% and 87.5% Brahman breed to 15.15, 19.87, 25.38 and 27.87 kg/calf, respectively. The differences among these groups were significant.

Thus, the results indicated that the BWs of crossbreds regularly increased with an increased proportion of Brahman breed in the crossbreds. This suggests that in the Western Highlands, it would be appropriate to raise crossbred beef herds with a high Brahman genetic proportion based on both LYC dams and RSC dams. However, the crossbreds based on RSC dams were better than those from LYC dams.

Average daily gain in different breed groups

The results in Table 6 indicate that the ADGs of almost all breed groups decreased with an increase in the age of the calves, with the exception of the 87.5BrLYC group. Notably, LYC had an average ADG of 281.77 g/calf/d for the age class 0–3 mth, whereas for the age class 3–6 mth, the average ADG was 281.86 g/calf/d, which decreased to 136.42 g/calf/d for the age class 18–24 mth. The average ADG in the 75BrLYC group reduced from 627.32 g/calf/d for the age class 0–3 mth to 255.11 g/calf/d for the age class 18–24 mth. The ADGs of LYC were always significantly lower than for all the other groups. The RSC calves had significantly higher ADGs than the LYC calves, but lower than the crossbred groups with the Brahman breed. At the same crossbreeding level, the ADGs of crossbreds based on LYC dams were usually lower than for crossbreds based on RSC dams. Increasing the proportion of Brahman genetic in crossbreds increased the ADGs for both the LYC and RSC dams. In all breed groups and crossbreds, the ADGs of the 87.5BrRSC group were always the highest for all age classes. However, the difference between this group and the 75BrRSC group was not significant in only two age periods: 0–3 mth (716.67 g/calf/d and 652.80 g/calf/d, respectively) and 3–6 mth (731.90 g/calf/d and 656.27 g/calf/d, respectively). In subsequent periods, although the AGDs were higher they were not significantly different.

The ADGs in the periods from birth to age 24 mth for LYC reached 235.46 g/calf/d, which was significantly lower than for RSC at 288.32 g/calf/d. In the crossbred groups with Brahman cattle, an increase in the Brahman genetic proportion increased the ADG, with the group with the highest ADG being 87.5BrRSC (561.34 g/calf/d). For the same crossbreeding level of Brahman genetic proportion, crossbred groups based on RSC dams always had higher ADGs than the crossbreds based on LYC dams.

The ADGs of the crossbred groups according to the Brahman genetic proportion based on the pooled groups of LYC and RSC dams showed that the ADGs gradually reduced with age (Table 7). For each trait, the ADGs of breed groups all increased with an increased Brahman genetic proportion in the crossbreds, with the differences always significant. For example: the ADG in the period from birth to 3 mth for the breed groups not crossbred with Brahman reached 316.67 g/calf/d, with the ADGs all gradually increasing with the contributed proportion of Brahman breed in the crossbreds. The highest ADG was produced by the 87.5% Brahman breed group (713.79 g/calf/d).

The crossbreds with a Brahman genetic proportion of 75% or above all had good ADGs based on both the LYC and RSC dam groups. Thus, it seemed that to develop fattened beef herds with good weight gain required crossbreds with 75% or more of Brahman breed.

Table 4 Body weight by breed group for various age classes

Breed group	BW0		BW3m		BW6m		BW12m		BW18m		BW24m	
	N	LSM±SE	N	LSM±SE	*n*	LSM±SE	*n*	LSM±SE	*n*	LSM±SE	*n*	LSM±SE
25BrLYC	22	14.23±0.66^{ac}	36	54.34±2.02^{a}	36	95.35±4.01^{a}	32	162.74±7.65^{a}	32	220.05±9.98^{ab}	28	251.97±13.42^{a}
25BrRSC	32	15.83±0.55^{ac}	32	66.85±2.13^{bc}	32	115.97±4.23^{bcd}	23	198.89±8.90^{bdf}	22	272.87±11.89^{cd}	22	317.77±14.16^{bcd}
50BrLYC	63	16.50±0.41^{a}	56	63.14±1.72^{b}	59	107.83±3.31^{ab}	56	189.59±6.06^{abc}	39	257.31±9.23^{ac}	37	304.02±11.96^{b}
50BrRSC	170	20.89±0.26^{bd}	216	72.19±0.99^{c}	239	125.41±1.76^{cd}	212	218.72±3.42^{de}	165	304.20±4.98^{d}	158	356.79±8.03^{cd}
75BrLYC	19	22.61±0.70^{d}	23	77.94±2.50^{cd}	23	131.45±4.97^{de}	21	217.48±9.35^{cef}	20	308.57±12.45^{de}	16	366.44±16.78^{de}
75BrRSC	76	26.14±0.38^{e}	219	85.19±1.00^{d}	219	146.38±1.95^{e}	215	258.52±3.60^{g}	218	341.31±4.71^{e}	205	409.96±7.77^{ef}
87.5BrRSC	61	27.97±0.41^{f}	108	93.57±1.26^{e}	108	161.54±2.47^{f}	99	283.46±4.62^{h}	98	368.71±6.12^{f}	93	432.71±8.74^{f}
LYC	38	11.39±0.52^{g}	151	37.01±1.05^{f}	151	63.14±2.08^{g}	149	109.77±3.92^{i}	150	158.01±5.17^{g}	153	181.63±7.99^{g}
RSC	30	13.94±0.58^{c}	145	46.28±1.13^{g}	145	78.99±2.23^{h}	145	136.21±4.13^{k}	146	194.33±5.46^{b}	146	222.23±8.32^{a}

Br = Brahman cattle; LYC = Local Yellow cattle; RSC = Red Sindhi crossbred; BW0 = body weight at birth; BW3m = body weight at 3 mth; BW6m = body weight at 6 mth; BW12m = body weight at 12 mth; BW18m = body weight at 18 mth; BW24m = body weight at 24 mth. LSM values in same column with different lowercase superscripts are significantly ($p < 0.05$) different.

Table 5 Body weights of breed groups in various age classes according to Brahman genetic proportion

Breed group	BW0		BW3m		BW6m		BW12m		BW18m		BW24m	
	N	LSM±SE	N	LSM±SE	N	LSM±SE	N	LSM±SE	N	LSM±SE	N	LSM±SE
0Br	68	12.54±0.47^{a}	296	41.25±0.88^{a}	296	70.57±1.72^{a}	294	121.77±3.30^{a}	296	174.37±4.40^{a}	299	201.58±7.62^{a}
25Br	54	15.15±0.49^{b}	68	59.79±1.57^{b}	68	104.54±3.09^{b}	55	176.76±6.13^{b}	54	240.04±8.10^{b}	50	280.53±11.04^{b}
50Br	233	19.87±0.27^{c}	272	70.34±0.98^{c}	298	122.29±1.73^{c}	268	212.52±3.32^{c}	204	294.43±4.83^{c}	195	347.80±8.08^{c}
75Br	95	25.38±0.40^{d}	242	83.99±1.01^{d}	242	144.33±1.94^{d}	236	253.37±3.59^{d}	238	336.60±4.71^{d}	221	406.13±7.99^{d}
87.5Br	61	27.87±0.46^{e}	108	93.14±1.32^{e}	108	161.02±2.56^{e}	99	282.19±4.79^{e}	98	366.97±6.35^{e}	93	432.40±9.08^{e}

Br = Brahman cattle; LSM = least square mean; BW0 = body weight at birth; BW3m = body weight at 3 mth; BW6m = body weight at 6 mth; BW12m = body weight at 12 mth; BW18m = body weight at 18 mth; BW24m = body weight at 24 mth; 0Br = 0% Brahman genetic proportion; 25Br = 25% Brahman genetic proportion; 50Br = 50% Brahman genetic proportion; 75Br = 75% Brahman genetic proportion; 87.5Br = 87.5% Brahman genetic proportion; LSM values in same column with different lowercase superscripts are significantly ($p < 0.05$) different.

Table 6 Average daily gain for various breed groups

Breed group	ADG0-3		ADG4-6		ADG7-12		ADG13-18		ADG19-24		ADG0-24	
	N	LSM±SE	N	LSM±SE	N	LSM±SE	N	LSM±SE	N	LSM±SE	N	LSM±SE
25BrLYC	36	441.34±22.32[a]	36	429.12±22.27[a]	32	396.74±21.84[ab]	32	328.08±19.66[abc]	28	243.02±18.78[a]	28	329.22±18.66[a]
25BrRSC	32	563.91±23.46[b]	32	523.19±23.41[abc]	23	500.88±25.31[cd]	22	428.92±23.40[de]	22	291.23±19.64[ab]	22	417.33±19.69[bc]
50BrLYC	56	522.34±18.95[ab]	56	483.53±18.91[ac]	52	446.49±18.18[ace]	39	390.23±18.16[ad]	35	242.69±17.17[ac]	37	397.98±16.62[bg]
50BrRSC	216	576.36±10.90[b]	216	553.16±10.88[b]	191	547.11±10.42[d]	165	484.24±9.80[e]	155	306.28±11.69[b]	158	465.95±11.17[c]
75BrLYC	23	627.32±27.56[bcd]	23	570.13±27.50[bcd]	21	531.21±26.61[de]	20	437.70±24.52[de]	16	255.11±23.32[abc]	16	477.29±23.33[cdg]
75BrRSC	219	652.80±11.06[c]	219	656.27±11.04[d]	215	642.34±10.43[f]	215	475.10±9.40[e]	205	399.03±11.29[d]	205	532.13±10.80[de]
87.5BrRSC	108	716.67±13.90[d]	108	731.90±13.87[e]	99	678.54±13.29[f]	94	494.33±12.38[e]	81	407.88±13.26[d]	93	561.34±12.15[e]
LYC	151	281.77±11.55[e]	151	281.86±11.52[f]	149	274.43±11.17[g]	149	266.06±10.20[b]	147	136.42±11.65[e]	153	235.46±11.10[f]
RSC	145	357.44±12.47[f]	145	348.01±12.44[g]	145	335.70±11.86[b]	145	327.66±10.79[c]	146	175.02±12.05[f]	146	288.32±11.57[a]

LSM = least square mean; ADG = average daily gain (in grams per calf per day); ADG0-3: ADG for period from birth to 3 mth; ADG4-6 = ADG for period 4–6 mth; ADG7-12 = ADG for period 7–12 mth; ADG13-18 = ADG for period 13–18 mth; ADG19-24 = for period 19–24 mth; ADG0-24 = ADG for period birth–24 mth; 25Br = 25% Brahman genetic proportion; 50Br = 50% Brahman genetic proportion; 75Br = 75% Brahman genetic proportion; 87.5Br = 87.5% Brahman genetic proportion.
LSM values in same column with different lowercase superscripts are significantly ($p < 0.05$) different.

Table 7 Average daily gain for various breed groups according to Brahman genetic proportion

Breed group	ADG0-3		ADG4-6		ADG7-12		ADG13-18		ADG19-24		ADG0-24	
	n	LSM±SE	*n*	LSM±SE	*n*	LSM±SE	*n*	LSM±SE	*n*	LSM±SE	*n*	LSM±SE
0Br	296	316.67±9.52[a]	296	311.87±9.51[a]	294	302.24±9.46[a]	294	294.04±8.63[a]	293	157.32±11.23[a]	299	261.46±10.53[a]
25Br	68	495.48±16.96[b]	68	470.36±16.94[b]	55	437.86±17.52[b]	54	366.75±15.86[b]	50	265.10±15.61[b]	50	367.53±15.27[b]
50Br	272	565.32±10.54[c]	272	538.74±10.53[c]	243	526.18±10.17[c]	204	465.19±9.44[c]	190	297.13±11.84[b]	195	454.39±11.17[c]
75Br	242	646.77±10.85[d]	242	644.19±10.84[d]	236	628.99±10.42[d]	235	468.77±9.34[c]	221	389.31±11.67[c]	221	527.32±11.05[d]
87.5Br	108	713.79±14.18[e]	108	728.54±14.16[e]	99	675.82±13.76[e]	94	491.62±12.76[c]	81	407.81±13.81[c]	93	561.01±12.56[e]

LSM = least square mean; ADG = average daily gain (in grams per calf per day); ADG0-3: ADG for period from birth to 3 mth; ADG4-6 = ADG for period 4–6 mth; ADG7-12 = ADG for period 7–12 mth; ADG13-18 = ADG for period 13–18 mth; ADG19-24 = for period 19–24 mth; ADG0-24 = ADG for period birth–24 mth; 0Br = 0% Brahman genetic proportion; 25Br = 25% Brahman genetic proportion; 50Br = 50% Brahman genetic proportion; 75Br = 75% Brahman genetic proportion; 87.5Br = 87.5% Brahman genetic proportion.
LSM values in same column with different lowercase superscripts are significantly ($p < 0.05$) different.

Increments in body weight and average daily gain

Increments in body weight of crossbreds from two dam groups

The increments in BW of the crossbreds based on the LYC and RSC dams and crossbred groups according to Brahman genetic proportions are shown in Table 8. The results indicated that all estimated values were significantly different in the different age classes based on LYC dams, RSC dams and the pooled dam group; consequently, all these coefficients were suitable for use with this dataset. There were increases in BW following crossbreeding between Brahman cattle with LYC dams and for an increase in the Brahman genetic proportion in these crossbred groups. The increment was the lowest at birth, for every 1% increase in Brahman breed in the crossbreds, with the birth weight increased by 0.14 kg. At age 24 mth, for every 1% increase in Brahman breed, the BW was enhanced by 2.43kg. Similarly, the BWs increased for crossbreeding with RSC dams and increasing the Brahman breed proportion in these crossbreds. At birth, for every 1% increase in Brahman breed, the birth weight increased by 0.17 kg. The increment level of BW increased with age class; at 24 mth a 1% increase in Brahman breed increased the BW by 2.30 kg.

For both LYC and RSC dams, for every 1% increase of Brahman breed, the BW increased by 0.18 kg and the increment was regular. At 24 mth, an increase of 1% Brahman breed in the crossbreds increased their BW by 2.62 kg. Thus, an increase in the Brahman breed proportion in the crossbreds linearly increased their BWs, which indicated that increasing the proportion of Brahman breed in cross breeding was a suitable strategy with LYC and RSC dams in the Western Highlands.

Increments of average daily gain in crossbred groups based on different dam groups

With the LYC dams, crossbreeding with Brahman in the period from birth to age 3 mth, an increase of 1% in the Brahman breed in the crossbreds increased the ADG by 4.47 g/d (Table 9). The increment tended to reduce in subsequent age classes, with the increment being only 1.42 g/d in the period 18–24 mth. On the other hand, the results indicated that the crossbreds based on RSC dams with increasing Brahman breed, in period from birth to age 3 mth, the ADG was 402.96 g/d with no Brahman breed genetic content (100% RSC); however, for a 1% increase in the Brahman breed proportion in the crossbreds, the ADG increased by 3.59 g/d. In the period 3–6 mth, the increment level was higher, reaching 3.98 g/d, whereas in the following stages, the increment decreased to 1.72 g/d for the period 12–18 mth, but increased again to 2.57g/d in the period 18–24 mth.

In the crossbred groups with pooled LYC and RSC dams, the calves with no Brahman breed content had an ADG in the period 0–3 mth of 347.77 g/d; however, a 1% increase in the Brahman breed in these calves produced an increment of 4.21 g/d. At 18–24 mth, a 1% increase in Brahman breed in the crossbreds produced an increment level in the ADG of 2.79 g/d. In the stage from birth to age 24 mth, the ADG increment based on the LYC dams reached 3.18 g/d, whereas for the RSC dams, the ADG increment reached 2.96 g/d. Estimating the increment in calves according to their Brahman genetic proportion resulted in an ADG increment of 3.39 g/d.

Discussion

The Brahman cattle breed has an the advantage in disease resistance compared to other high-yielding beef breeds, with the low cost of veterinary medicine and good utilization of natural grass (Armelinda et al., 2018). Brahman cattle may be a good genetic resource heritage for some countries develop beef production (Papry et al., 2020). Several researchers have reported that the Brahman genetic resource has been utilized to increase productivity, as well as promoting the environmental adaptability of crossbreds. Including various grades of the Brahman genetic resource into crossbreds gave dominant superiority to heat tolerance and heat stress (Hammond et al., 1996; Dikmen et al., 2018; Davila et al., 2019; Mateescu et al., 2020). In addition, other researchers revealed that including 25–75% of the Brahman genetic resource into reproductive cow herds helped the cattle to adapt better to hot, humid climates, such as in Florida, where the cattle with 25% Brahman breed could better tolerate the climate than Taurine cattle and that cattle with 75% Brahman breed had the same level of tolerance as pure Brahman cattle (Davila et al., 2021). In Bangladesh, Brahman genetic resource was utilized to intensify performance and improve muscular weight in crossbred calves with 25% Brahman genetic resource with a birth weight of 18.52–18.83 kg/calf at age 12 mth to achieve BWs in the range 153.45–172.68 kg/calf, with ADGs from birth to age 12 mth reaching 369.73–421.48 g/calf/d, respectively, in two systems that were much higher than in their native cattle (Papry et al., 2020). Other interesting research showed that increasing the Brahman genetic resource proportion from 50% to 100% in crossbreds increased the weaning weight by 15.9 kg. Furthermore, calves with similar Brahman genetic proportions but born from dams with different Brahman genetic proportions had different birth weights but only by a small amount (Holmes et al., 1992).

Table 8 Increment in body weight for calves in different age classes of various dam groups for 1% increase in Brahman breed

Trait	P	LYC dam					RSC dam					Pooled dam group				
		DF	E	SE_E	t Value	Pr > |t|	DF	E	SE_E	t Value	Pr > |t|	DF	E	SE_E	t value	Pr > |t|
BW0	a	1	10.80	1.13	9.55	0.0108	1	12.88	0.85	15.2	0.0006	1	11.58	0.75	15.39	0.0006
	b	1	0.14	0.02	5.95	0.0271	1	0.17	0.01	11.49	0.0014	1	0.18	0.01	13.76	0.0008
BW3m	a	1	38.37	2.06	18.61	0.0029	1	49.05	2.98	16.46	0.0005	1	42.76	1.68	25.40	0.0001
	b	1	0.53	0.04	11.94	0.0069	1	0.50	0.05	9.61	0.0024	1	0.57	0.03	19.30	0.0003
BW6m	a	1	66.83	4.81	13.89	0.0051	1	84.51	5.53	15.28	0.0006	1	74.10	3.59	20.64	0.0002
	b	1	0.87	0.10	8.45	0.0137	1	0.87	0.10	8.97	0.0029	1	0.98	0.06	15.60	0.0006
BW12m	a	1	117.40	8.24	14.24	0.0049	1	144.56	8.43	17.15	0.0004	1	125.67	4.42	28.42	<0.0001
	b	1	1.40	0.18	7.95	0.0155	1	1.57	0.15	10.68	0.0018	1	1.76	0.08	22.81	0.0002
BW18m	a	1	162.64	6.04	26.92	0.0014	1	208.01	11.10	18.74	0.0003	1	180.64	5.49	32.89	<0.0001
	b	1	1.96	0.13	15.14	0.0043	1	1.86	0.19	9.59	0.0024	1	2.14	0.10	22.36	0.0002
BW24m	a	1	185.05	4.45	41.55	0.0006	1	238.82	13.06	18.28	0.0004	1	209.06	6.31	33.14	<0.0001
	b	1	2.43	0.10	25.48	0.0015	1	2.30	0.23	10.07	0.0021	1	2.62	0.11	23.83	0.0002

BW0 = body weight at birth; BW3m = body weight at 3 mth; BW6m = body weight at 6 mth; BW12m = body weight at 12 mth; BW18m = body weight at 18 mth; BW24m = body weight at 24 mth; P = parameters; a = intercept coefficient (basic body weight in kilograms), b = slope (increment in body weight in kilograms) for a 1% increase in Brahman breed in crossbreds; DF = degrees of freedom; E = Estimators of coefficients (P).

Table 9 Increment in average daily gain for calves in various dam groups for 1% increase in Brahman breed

Trait	LYC dam						RSC dam					Pooled dam group				
	Parameter	DF	P	SE_P	t Value	Pr > |t|	DF	P	SE_P	t Value	Pr > |t|	DF	P	SE_P	t Value	Pr > |t|
ADG0-3	a	1	300.54	21.09	14.25	0.0049	1	402.96	40.16	10.03	0.0021	1	347.77	25.75	13.51	0.0009
	b	1	4.47	0.45	9.92	0.0100	1	3.59	0.70	5.12	0.0144	1	4.21	0.45	9.36	0.0026
ADG4-6	a	1	303.28	24.41	12.43	0.0064	1	373.40	28.82	12.96	0.001	1	327.36	19.59	16.71	0.0005
	b	1	3.68	0.52	7.05	0.0196	1	3.98	0.50	7.91	0.0042	1	4.45	0.34	13.01	0.001
ADG7-12	a	1	289.20	18.06	16.02	0.0039	1	365.21	24.68	14.80	0.0007	1	315.53	10.61	29.75	<0.0001
	b	1	3.28	0.39	8.50	0.0136	1	3.70	0.43	8.59	0.0033	1	4.18	0.19	22.59	0.0002
ADG13-18	a	1	268.96	4.73	56.87	0.0003	1	360.17	27.85	12.93	0.001	1	310.69	22.67	13.70	0.0008
	b	1	2.31	0.10	22.83	0.0019	1	1.72	0.49	3.55	0.0382	1	2.24	0.40	5.67	0.0109
ADG19-24	a	1	165.95	32.04	5.18	0.0353	1	193.66	20.57	9.41	0.0025	1	170.58	15.28	11.16	0.0015
	b	1	1.42	0.69	2.08	0.1734	1	2.57	0.36	7.17	0.0056	1	2.79	0.27	10.48	0.0019
ADG0-24	a	1	240.85	6.35	37.90	0.0007	1	312.44	18.90	16.53	0.0005	1	273.18	9.73	28.07	<0.0001
	b	1	3.18	0.14	23.39	0.0018	1	2.96	0.33	8.97	0.0029	1	3.39	0.17	19.97	0.0003

Br = Brahman cattle; LYC = Local Yellow cattle; RSC = Red Sindhi crossbred; P = parameters; a = intercept coefficient (basic body weight in kilograms), b = slope (increment in body weight in kilograms) for a 1% increase in Brahman breed in crossbreds; DF = degrees of freedom; P = Estimators for Parameters.

Some researchers reported that crossbreds with 50% Brahman genetic resource could reach a BW from 23.89 kg/calf at birth to 265.73 kg/calf for males and from 22.85 kg/calf to 251.06 kg/calf for females, while ADG values for different stages from birth to age 12 mth ranged from 397.15 g/d to 928.75 g/d for males and from 392.89 g/d to 860.21 g/d for females. In addition, BW and ADG were affected by seasons and locations (Mahbubul and Hoque, 2020).

The findings of Haque et al. (2016) in Bangladesh indicated that the crossbreds with 50% Brahman breed got BW and ADG usually higher than crossbreds with 25% Brahman breed at birth and 12 months old (21.40 kg/calf at birth and 229.62 kg/calf at 12 months old in crossbreds with 50% Brahman breed, in comparison to 18.59 kg/calf at birth and 209.29 kg/calf at 12 months old in 25% Brahman crossbreds); whereas, ADG values from birth to age 12 mth in 50% Brahman crossbreds averaged 570.52 g/d, which was higher than the 529.98 g/d for 25% Brahman crossbreds.

Brahman genetic resource had a favorable impact on BW and ADG but impacted poorly on beef quality with an increase in the Brahman breed proportion in crossbreds increasing beef toughness and decreasing tenderness, juiciness and linkage tissue (Phelps et al., 2017).

The current research on the performance traits of crossbreds with the Brahman breed were improved compared to groups without any Brahman genetic input. Specifically, increasing the Brahman genetic proportion in crossbreds positively improved their growth performance in a linear relationship. The better growth performance of crossbreds based on RSC compared to LYC was explained by the contribution of Red Sindhy in crossbreeding. These findings suggested that upgrading LYC and RSC dams with genetic input from the Brahman breed would benefit productivity and should taken into account in the breeding of beef cattle herds in the Western Highlands. The crossbreds with 75% Brahman breed had a much better growth rate than groups with a low Brahman breed proportion (over 500g/d in the stage from birth to age 24 mth). However, many of the cattle famers in the Western Highlands have limited economic resources with most of them coming from ethnic minority groups, so it would be difficult for them to improve their breeding stock with a high Brahman genetic proportion because of the investment and the knowledge required. Therefore, 75% Brahman genetic crossbreds appeared to be the most suitable and adaptable to develop extensively in the Western Highlands. The current results showed that a crossbred group involving 50% Brahman input was suitable for small-scale farmers, with 75% or above for commercial fattening systems because these levels would produce high performance and optimal economic efficiency under productive conditions for numerous systems. However, the effects of Brahman genetic resource on beef quality in crossbreds should be researched further.

In conclusion, beef cattle upgraded with Brahman genetic resources should be appropriate in the Western Highlands based on both Local Yellow and Red Sindhi crossbred cows due the positive impact on BW and ADG in the crossbreds. While the crossbred group with a high Brahman genetic proportion had a fast growth rate, for the productive conditions on the Western Highlands, crossbreds with more than 50% Brahman breed should be utilized in feedlot systems.

Conflict of Interest

The authors declare that there are no conflicts of interest.

Acknowledgements

The Ministry of Agriculture and Rural Development provided funding and financial support. The Directorate Board of the National Institute of Animal Science and personnel in the Agricultural Department in Dak-Lak and Gia-Lai provinces and cattle farmers all provided valuable cooperation.

References

Ahammed, M., Akter, T., Nooruzzaman, M., Alam, M.R., Islam, M.T., Chowdhur, E.H. 2020. Superior performance of the Brahma cattle in terms of meat production and disease resistance in comparison with the indigenous cattle of Bangladesh. Bangl. J. Vet. Med. 18: 59–63. doi.org/10.33109/bjvmjd2020rm5

Alvarez, P., Spicer, L.J., Chase, C.C. Jr, et al. 2000. Ovarian and endocrine characteristics during an estrous cycle in Angus, Brahman, and Senepol cows in a subtropical environment. J. Anim. Sci. 78: 1291–1302. doi.org/10.2527/2000.7851291x

Armelinda, I., Carolyn, F., Joe, P. 2018. Achieving Reproductive Success Utilizing the American Brahman Cow. ABBA Workshop. Hanoi, Vietnam.

Cassidy, W. 2015. Genetic resistance to parasites: An option besides chemicals? https://www.progressivecattle.com/topics/reproduction/genetic-resistance-to-parasites-an-option-besides-chemicals, 24 February 2015.

Collier, R.J., Gebremedhin, K.G. 2015. Thermal biology of domestic animals. Annu. Rev. Anim. Biosci. 3: 513–532. doi.org/10.1146/annurev-animal-022114-110659

Davila, K.S., Hamblen, H., Dikmen, S., Hansen, P., Thrift, T., Mateescu, R. 2021. Incorporating Brahman genetics in the cow herd to alleviate heat stress. EDIS 2021: AN366. https://doi.org/10.32473/edis-an366-2021

Davila, K.M.S., Hamblen, H., Hansen, P.J., Dikmen, S., Oltenacu, P.A., Mateescu, R.G. 2019. Genetic parameters for hair characteristics and core body temperature in a multibreed Brahman-Angus herd. J. Anim. Sci. 97: 3246–3252. doi.org/10.1093/jas/skz188

Department of Water Resources Management. 2019 Agriculture in the central highlands adapts to climate change - Lesson 1: The weather is getting more and more extreme. http://dwrm.gov.vn/index, 12 November 2019.

Dikmen, S., Mateescu, R.G., Elzo, M.A., Hansen, P.J. 2018. Determination of the optimum contribution of Brahman genetics in an Angus-Brahman multibreed herd for regulation of body temperature during hot weather. J. Anim. Sci. 96: 2175–2183. doi.org/10.1093/jas/sky133.

Finch, V. A. 1985. Comparison of non-evaporative heat transfer in different cattle breeds. Aust. J. Agric. Res. 36: 497–508. doi.org/10.1071/AR9850497.

Giang, H. 2017. Ruminant production in middle land and western highlands: Potentials and Challenges. https://nhachannuoi.vn/chan-nuoi-dai-gia-suc-o-mien-trung-va-tay-nguyen-tiem-nang-va-thach-thuc. 2 November 2017. [in Vietnamese]

Hai, D.V., Trinh, N.T.H., Chung, L.B., Quan, P.M. 2019. Growth performance of beef crossbred calves from birth to 6 months old nourished in households in Ben-Cat town, Binh-Duong province. Journal of Animal Science and Technology 101: 34–45. [in Vietnamese]

Hai, V.D., Con, T.V., Quat, N.X., et al. 2009. Upland field cultivation of some ethnic minorities in the Western Highlands and policies and solutions for reasonable use of forest land. Vietnam Forestry Science Institute. http://vafs.gov.vn/vn, 24 March. 2009. [in Vietnamese]

Hammond, A.C., Olson, T.A. 1994. Rectal temperature and grazing time in selected beef cattle breeds under tropical summer conditions in subtropical Florida. Trop. Agric. 71: 128–134.

Hammond, A.C., Olson, T.A., Chase, C.C. Jr., Bowers, E.J., Randel, R.D., Murphy, C.N., Vogt, D.W., Tewolde, A. 1996. Heat tolerance in two tropically adapted *Bos taurus* breeds, Senepol and Romosinuano, compared with Brahman, Angus, and Hereford cattle in Florida. J. Anim. Sci. 74: 295–303. doi.org/10.2527/1996.742295x

Hansen, P.J. 2004. Physiological and cellular adaptations of zebu cattle to thermal stress. Anim. Reprod. Sci. 82–83: 349–360. doi.org/10.1016/j.anireprosci.2004.04.011

Haque, M.A., Fatematuzzohora, M., Hoque, M.A., Ali, M.Y. 2016. Evaluation of growth performance of Brahman cross calves to local environment of Bangladesh. Asian J. Med. Biol. Res. 2: 259–265. doi: 10.3329/ajmbr.v2i2.29069

Hohenboken, W.D. 1987. Behavioral genetics. Vet. Clin. North Am. Food Anim. Pract. 3: 217–229. doi.org/10.1016/S0749-0720(15)31149-X

Holmes, J., McKinnon, M., Seifert, G., Schottler, J. 1992. Comparison of Afrikaner- and Brahman- cross cattle in Papua New Guinea. Asian Australas. J. Anim. Sci. 5: 419–426. doi.org/10.5713/ajas.1992.419.

Hue, M. 2020. Wake up potentials for Livestock production of Western Highlands (Lesson 2): “Gold land” setting up safe zone for pandemic. https://danviet.vn/danh-thuc-tiem-nang-chan-nuoi-cua-tay-nguyen-bai-2-dat-vang-xay-dung-vung-an-toan-dich-benh-20200728164948823.htm, 29 July 2020. [in Vietnamese]

Huong, L. 2023. Celebration of cattle fighting of H’Mong ethnic group in Western Highland. baodantoc.vn. Vietnam. [in Vietnamese]

Huong, L., Trong, P. 2021. Animal husbandry – Opportunities to escape poverty for Western Highland’s farmers: Optimistic signals (Lesson 1). baodantoc.vn. Vietnam. [in Vietnamese]

Huy, Q. 2017. Provinces in western highland turned large livestock production into commodity production industry. https://dangcongsan.vn/kinh-te/cac-tinh-tay-nguyen-dua-chan-nuoi-dai-gia-suc-thanh-nganh-san-xuat-hang-hoa, 12 April 2017. [in Vietnamese]

International Committee for Animal Recording. 2020. International agreement of recording practices: Guidelines approved by the General Assembly. http://pecuaria.pt/docs/Guidelines_2014.pdf, 11 August 2020.

Koger, M. 1963. Breeding for the American tropics. In: Cunha, T.J., Koger, M., Warnick, A.C. (Eds.). Crossbreeding Beef Cattle. Series I. University of Florida Press. Gainesville, FL, USA, pp. 41–46.

Kuswati, K., Susilawati, T.N., Rosyidi, D., Artono, K., Journals, I., Agus, A., Kuswati, K.T. 2014. Carcass characteristics of Brahman crossbred cattle in Indonesian Feedlot. J. Agric. Vet. Sci. 7: 19–24.

La, T., Binh, N.V., Quang, V.T. 2017. Growth performance of high yielding crossbred couples among Red Sindhi crossbred cows and Brahman, Droughtmaster and Red Angus bulls nourished in Lam-Dong province. Journal of Vietnam Agricultural Science and Technology 9: 116–120. [in Vietnamese]

Linh, N.T.M., Dung, D.V., Long, T.N., Phong, V.N., Phung, L.D., Son, P.H., Ba, N.X. 2020. Feed intake and growth performance of three crossbred combinations of Charolais, Droughtmaster and Red Angus bulls with Brahman crossbred cows raised in households in Quang-Ngai province. Journal of Agriculture and Rural Development 398: 96–108. [in Vietnamese]

Mahbubul, M., Hoque, M.A. 2020. Effect of non-genetic factors on growth performance of Brahman crossbred cattle of Bangladesh. Fundam. Appl. Agric. 5: 421–428.

Mateescu, R.G., Sarlo-Davila, K.M., Dikmen, S., Rodriguez, E., Oltenacu, P.A. 2020. The effect of Brahman genes on body temperature plasticity of heifers on pasture under heat stress. J Anim. Sci. 98: skaa126. doi.org/10.1093/jas/skaa126

Moran, J. 1970. Brahman cattle in a temperate environment: II. Adaptability and grazing behaviour. J. Agric. Sci. 74: 323–327. doi.org/10.1017/S0021859600022942

National Institute of Animal Science. 2001. Ingredients and Nutritional Values of Animal Feed Resources for Livestock in Vietnam. Agricultural Publication House in Hanoi. Hanoi, Vietnam. [in Vietnamese].

Papry, K., Shejuty, S., Bhuiyan, A., Hoque, M. 2020. Growth performance of graded Brahman calves in selected areas of Mymensingh district. J. Bangladesh Agric. Univ. 18: 435–441.

Phelps, K.J., Johnson, D.D., Elzo, M.A., Paulk, C.B., Gonzalez, J.M. 2017. Effect of Brahman genetics on myofibrillar protein degradation, collagen crosslinking, and tenderness of the longissimus lumborum. J. Anim. Sci. 95: 5397–5406. doi.org/10.2527/jas2017.2022.

Phuong, T., Nguyet, M. 2015. Drought in the central-central highlands will last longer and be more severe. https://www.vietnamplus.vn/han-han-o-mien-trungtay-nguyen-se-keo-dai-va-khac-nghiet-hon/334970.vnp, 28 July 2015.

Quyen, P.V., Cam, T.T., Hieu, L.T.M., Sal, G.V., Hung, B.N. 2018. Productivity of beef cattle F_1 Red Angus × Red Sindhi crossbreds and F_1 Brahman × Red Sindhi crossbreds in Tay-Ninh province. Journal of Animal Science and Technology 86: 19–34. [in Vietnamese]

Quyen, P.V. 2021. Productivity of Brahman cattle and some beef crossbred groups in Tra-Vinh province. Journal of Animal Husbandry Science and Technics 266: 40. [in Vietnamese]

Rechav, Y., Dauth, J., Els, D.A. 1990. Resistance of Brahman and Simmentaler cattle to Southern African ticks. Onderstepoort J. Vet. Res. 57: 7–12.

Riley, D.G., Chase, J.C., Coleman, S.W., Olson, T.A. 2012. Genetic assessment of rectal temperature and coat score in Brahman, Angus, and Romosinuano crossbred and straightbred cows and calves under subtropical summer conditions. Livest. Sci. 148: 109–118. doi.org/10.1016/j.livsci.2012.05.017

Schutt, K.M., Burrow, H.M., Thompson, J.M., Bindon, B.M. 2009. Brahman and Brahman crossbred cattle grown on pasture and in feedlots in subtropical and temperate Australia. 2. Meat quality and palatability. Anim. Prod. Sci. 49: 439–451.

Svotwa, E., Makarau, A., Hamudikuwanda, H. 2007. Heat tolerance of Mashona, Brahman and Simmental cattle breeds under warm humid summer conditions of natural region II area of ZImbabew. Elec. J. Env. Agricult. Food Chem. 6: 1934–1944.

Tai, V.A. 2021. Research improvement, management for natural grass carpet and feed processing from available materials to serve development of large ruminants (Buffaloes, cattle, elephants) with intensive system and hold scales to crate sustainable livelihood for farmers in Western Highlands. Final Report of National Project, Code number: TN17/T05 under Western Highlands Programme 2016–2020.

Tessema, T., Sopannarath, P., Tumwasorn, S., Raungprim, T. 2013. Genetic parameters for weaning weight, weaning hip height and weaning body length of crossbred beef cattle in Thailand. Kasetsart J. (Nat. Sci.) 47: 85–93.

Thrift, F.A., Thrift, T.A. 2003. Longevity attributes of *Bos indicus* × *Bos taurus* crossbred cows. Prof. Anim. Sci. 19: 329–341. doi.org/10.15232/S1080-7446(15)31438-8

Waritthitham, A., Lambertz, C., Langholz, H.J., Wicke, M., Gauly, M. 2010. Assessment of beef production from Brahman × Thai native and Charolais × Thai native crossbred bulls slaughtered at different weights. II: Meat quality. Meat Sci. 85: 196–200. doi.org/10.1016/j.meatsci.2009.12.025