Effect of weaning weight on growth performance, feed efficiency, and behavioral characteristics of Holstein-Friesian and Brown Swiss calves

Efecto del peso al destete sobre el rendimiento del crecimiento, la eficiencia alimenticia y las características de comportamiento de terneros Holstein-Friesian y Pardo suizo

Efeitos do pesos au desmame no desempenho de crescimento, eficiência alimentar e características comportamentais de bezerros Holstein-Friesian e Pardo suíço

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Abstract

Background: Farm profitability depends on raising healthy calves, which rests on successful feeding and management programs. **Objective:** To determine the effects of weaning weight on growth performance, feed efficiency, behavioral traits, as well as feeding cost of Holstein-Friesian and Brown Swiss calves. **Methods:** Sixty-seven newborn dairy calves were allocated into four weaning-weight groups [60 kg (n=18), 65 kg (n=19), 70 kg (n=18) and 75 kg (n=12)]. Body weights (BW) and measurements were recorded at birth, weaning, and four months of age. An instantaneous sampling method was used to collect behavioral data. **Results:** Daily weight gain of Brown Swiss calves was higher than Holsteins between weaning and four months of age ($p<0.05$). During pre-weaning, daily weight gain of calves weaned at 60 kg was lower than the other three groups ($p<0.05$). Feed efficiency of Holstein-Friesian was higher than Brown Swiss calves in the period between birth and four months of age ($p<0.05$). Chest depth of calves weaned at 60 kg was ($p<0.05$) lower compared to the other groups. Water drinking behavior during the pre-weaning period was notably higher in calves weaned at 75 kg ($p<0.05$). **Conclusions:** Our results suggest that dairy calves can be weaned at 60 kg of BW without detrimental effects on performance, and their feed cost per kg weight gain is significantly lower compared to higher weaning weights.

Keywords: *behavior; Brown Swiss; cattle; dairy calves; feed efficiency; feeding cost; growth performance; Holstein-Friesian; weaning weight.*

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Resumen

Antecedentes: La crianza de terneros sanos es uno de los principales requisitos para asegurar la rentabilidad de la granja, y depende en gran medida del éxito en los programas de alimentación y manejo de los terneros. **Objetivo:** Determinar los efectos del peso al destete sobre el rendimiento del crecimiento, la eficiencia alimenticia, las características de comportamiento y el costo de alimentación de terneros Holstein-Friesian y Pardo suizo. **Métodos:** Sesenta y siete terneros lecheros recién nacidos se distribuyeron en cuatro grupos diferentes de peso al destete [60 kg (n=18), 65 kg (n=19), 70 kg (n=18) y 75 kg (n=12)]. Los pesos y medidas corporales se registraron al nacimiento, al destete, y a los cuatro meses de edad. Se utilizó un método de muestreo instantáneo para recopilar los datos de comportamiento. **Resultados:** La ganancia diaria de peso de los terneros Pardo suizo entre el destete y los cuatro meses de edad fue mayor que la de los Holstein-Friesian (p<0,05). Además, las ganancias diarias de peso de los terneros destetados con 60 kg de peso corporal (PC) fueron menores que las de los otros tres grupos durante el período previo al destete (p<0,05). La eficiencia alimenticia de los terneros Holstein-Friesian fue mayor que la de los Pardo suizo en el período entre nacimiento y cuatro meses de edad (p<0,05). La profundidad del pecho de los terneros en el grupo destetado a 60 kg fue menor que en otros grupos (p<0,05). El comportamiento de consumo de agua fue notablemente superior en los terneros destetados a 75 kg de PC durante el período previo al destete (p<0,05). **Conclusiones:** Nuestros resultados sugieren que los terneros lecheros pueden destetarse a los 60 kg de PC sin efectos perjudiciales sobre su rendimiento, y su costo de alimento por 1 kg de aumento de peso es significativamente menor en comparación con mayores pesos de destete.

Palabras clave: *comportamiento; costo de alimentación; eficiencia alimenticia; ganado; Holstein-Friesian; Pardo suizo; peso al destete; rendimiento de crecimiento; terneros lecheros.*

Resumo

Antecedentes: A criação de bezerros saudáveis é um dos principais requisitos para garantir a rentabilidade dos empreendimentos e depende muito do sucesso nos programas de alimentação e manejo dos bezerros. **Objetivo:** Determinar os efeitos do peso ao desmame sobre o desempenho de crescimento, eficiência alimentar, características comportamentais e custo de alimentação de bezerros da raça Holstein-Friesian e Pardo suíço. **Métodos:** Sessenta e sete bezerros recém-nascidos foram alocados em quatro diferentes grupos de peso ao desmame [60 kg (n=18), 65 kg (n=19), 70 kg (n=18) e 75 kg (n=12)]. Os pesos e medidas corporais foram determinados ao nascimento, desmame e 4 meses de idade. O método de amostragem instantânea foi utilizado para coletar os dados comportamentais. **Resultados:** O ganho de peso diário dos bezerros Pardos suíços entre o desmame e os 4 meses de idade foi significativamente maior do que os da Holstein-Friesian (p<0,05). Além disso, o ganho de peso diário dos bezerros desmamados com 60 kg de peso corporal (PC) foi significativamente (p<0,05) menor do que os outros três grupos no período pré-desmame. A eficiência alimentar dos bezerros Holstein-Friesian foi significativamente maior do que a dos bezerros Pardo suíço nos períodos entre o nascimento e os 4 meses de idade (p<0,05). O crescimento na profundidade do peito dos bezerros do grupo desmamado com 60 kg de PC foi significativamente (p<0,05) menor do que os demais grupos. Apenas o comportamento de beber foi notavelmente maior (p<0,05) nos bezerros desmamados com 75 kg de PC no período pré-desmame. **Conclusões:** Os resultados deste estudo sugerem que bezerros leiteiros podem ser desmamados com 60 kg de PC sem qualquer efeito prejudicial sobre seu desempenho e o custo de alimentação para ganho de peso de 1 kg é significativamente menor em comparação com pesos de desmame avançado.

Palavras-chave: *bezerros leiteiros; comportamento; custo da alimentação; desempenho de crescimento; eficiência alimentar; gado; Holstein-Friesian; Pardo suíço; pesos de desmame.*

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Introduction

Calf morbidity and mortality are major problems for dairy cattle farms worldwide (Romha, 2014). Raising healthy calves is one of the main requirements to ensure farm profitability, and it depends highly on successful calf feeding and management programs. The rate of calf mortality is estimated to be over 10% in Turkey and 5-10% in Europe (Küçükoflaz *et al.*, 2022).

Calves are born as monogastric animals since their rumen is not fully developed and functional. Thus, milk is the main source of nutrients for the newborn calves. Initiation of rumen activity is only possible by consumption of solid feed, such as starter diets. Transition from milk to solid feed is a major cause of stress for calves especially when the rumen is not fully prepared for digesting solid feeds. However, in dairy cattle farms, the pre-weaning period is intended to be as short as possible since milk is the primary source of income. If calves are raised together with their dams, the milk feeding period takes approximately 10 months (Eckert *et al.*, 2015). While weaning at a greater age causes economic losses for the farm, early weaning may result in deficiencies related to growth, development, health, and performance of calves due to poor nutrient supply during pre-weaning (Khattak *et al.*, 2018). Hence, several studies have been conducted to determine the optimum weaning time of dairy calves (Kehoe *et al.*, 2007; Laswai *et al.*, 2007; Passillé *et al.*, 2011; Özkaya and Toker, 2012; Koçyiğit *et al.*, 2015; Khattak *et al.*, 2018; McCoard *et al.*, 2019; Schwarzkopf *et al.*, 2019; Schwarzkopf *et al.*, 2022).

Early-weaning methods are based on encouraging calves to consume solid feed by keeping milk constant at 10% of calves' birth weight (Özhan *et al.*, 2001). Several weaning methods are widely used in dairy farms, most of which focus on age or certain amount of feed consumed by calves to stop milk feeding. In intensive dairy cattle farms weaning is performed mostly when calves are 7-8 weeks of age (Schwarzkopf *et al.*, 2019; Palczynski *et al.*, 2020). It is also common to wean calves when their daily starter feed consumption reaches over 750-1000 g in two consecutive days (Koçak and Güneş, 2005). Even though feed consumption may provide an idea about rumen development, the age of a calf alone is not enough to decide whether it is ready to be weaned. Weaning calves according to body weight (BW) instead of age was first suggested by Bell (1958). This method could be more appropriate since the physiological age of calves is equalized. However, it is not widely practiced and there is little information about it. Therefore, the aim of this study was to determine the effect of weaning weight on growth performance, feed efficiency, and behavioral traits, as well as the feed cost of dairy calves.

Materials and Methods

This study was performed with ethical approval from the Animal Experiments Local Ethics Committee of Ataturk University (Erzurum, Turkey; approval no. 36643897-95). The study was carried out at the research farm of the Food and Livestock Application and Research Center of Atatürk University, at Erzurum, Turkey. Sixty-seven newborn purebred dairy calves [Holstein-Friesian (n=37) and Brown Swiss (n=19)] were used in the study. For the first three days after birth, the calves were housed together with their dams to receive colostrum. Subsequently, they were randomly allocated into four weaning weight groups [weaning at 60 kg (n=18), 65 kg (n=19), 70 kg (n=18) and 75 kg (n=12)]. The calves were housed in individual pens equipped with feeders and water buckets. Each pen was 150 cm long and 120 cm wide. Straw bedding was provided to the calves. Straw was replaced daily to keep the bedding clean and dry.

Calves were fed milk form plastic bottles until weaning. The amount of milk offered was kept constant at 10% of birth weight until weaning, as suggested by Eckert *et al.* (2015). Calves were fed milk twice a day and had *ad libitum* access to water. From birth to the end of the study starter feed and dry hay were available in the pens. The starter feed offered contained barley grain (30%), wheat bran (20%), wheat grain (10%), molasses (5.7%), cotton meal (30%), salt (1%), limestone

(3%), vitamin premix (0.2%), and trace mineral mixture (0.1%). The chemical composition of the feeds used in the study is presented in Table 1. Calves were offered starter feed and dry hay every morning and the leftovers from the previous day were weighed and recorded to determine consumption.

Table 1. Characterization of the patients.

Nutrient	Starter feed (%)	Dry hay (%)
Dry matter	88.0	88.4
Crude protein	18.4	7.3
Ether extract	4.4	3.2
Cellulose	11.8	29.2
Ash	8.5	8.2

Body weights and measurements including chest depth, body length, height at withers, fore shank circumference, and hearth girth were measured and recorded at birth, weaning and four months of age. A measuring stick and a tape were used to determine body measurements. A 10-g precision scale was used to weight the calves.

The instantaneous sampling method was used to collect behavioral data (Kartal and Yanar, 2011). Behavior was recorded for each of the following activities: eating (head of the calf is in the feeder), drinking water (head of the calf is in the water bucket), lying (calf is lying on the ground), standing (calf is standing still). Throughout the study, calf behavior was determined and recorded weekly by walking from 9 to 12 a.m. through the calf barn at least 2 m from the pens, at 15-min intervals. The scores obtained for each activity were divided into the total behaviors and the results were multiplied by 100 to calculate percentage of time spent in each behavior.

Statistical analysis

A completely randomized 4×2×2 factorial design was used. Interactions among main factors were not statistically significant. Thus, only the main effects were statistically analyzed. The analysis of variance (GLM) available in the SPSS (2011) version 20.0 statistics program was used.

The statistical model used in the study is as follows (Yıldız and Bircan, 2008):

$$Y_{ijkl} = \mu + a_i + b_j + c_k + e_{ijkl}$$

Where:

Y_{ijk} = measurement of a particular trait,

μ = the population mean,

a_i = effect of weaning weight [i = 1 (60), 2 (65), 3 (70), 4 (75)],

b_j = effect of breed [j = 1 (BS), 2 (H)],

c_k = effect of sex [k = 1 (male), 2 (female)],

e_{ijkl} = random error

When the *F*-test for main effect was statistically significant, comparison among weaning weights was carried out by the method of Duncan's Multiple Range Test available in the SPSS program (SPSS, 2011).

Results

Least square means and standard errors for weight and daily weight gain of calves are presented in Table 2. There was no significant difference between breeds in terms of weight at birth and at four months of age. However, daily weight gain of Brown Swiss calves between weaning and four months of age was significantly higher than Holstein calves ($p<0.05$). Sex had no effect on weight or weight gain. No significant difference was observed among the four weaning weight groups in terms of weight at birth and four months of age as well as daily weight gain from birth and weaning to four months of age. Nevertheless, daily weight gain of calves weaned at 60 kg of BW was significantly ($p<0.05$) lower than the other three groups during the pre-weaning period.

Feed efficiency at different time periods is shown in Table 3. While breed had no significant effect on feed efficiency during pre-weaning, feed conversion ratio of Holstein-Friesian was significantly higher than Brown Swiss calves between weaning and four months of age, as well as between birth and four months of age ($p<0.05$).

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Table 2. Weight and daily weight gain of calves.

		Weight (kg)		Daily weight gain (kg)		
		Birth	4 months	Pre-weaning	Between weaning and 4 months of age	Between birth and 4 months of age
	N	X±SE	X±SE	X±SE	X±SE	X±SE
Breed		NS	NS	NS	*	NS
Brown Swiss	26	38.124±1.128	114.527±2.859	0.433±0.012	0.977±0.061	0.637±0.023
Holstein-Friesian	41	36.355±0.878	108.946±2.225	0.451±0.010	0.815±0.047	0.605±0.018
Sex		NS	NS	NS	NS	NS
Female	27	36.445±1.095	111.626±2.773	0.448±0.012	0.928±0.059	0.627±0.022
Male	40	38.034±0.903	111.847±2.288	0.437±0.010	0.864±0.049	0.615±0.018
Weaning weight (kg)		NS	NS	*	NS	NS
60	18	36.631±1.329	109.151±3.367	0.399±0.014[a]	0.845±0.071	0.604±0.027
65	19	36.067±1.285	109.160±3.256	0.446±0.014[b]	0.834±0.069	0.609±0.026
70	18	37.699±1.322	115.508±3.349	0.458±0.014[b]	0.931±0.071	0.648±0.027
75	12	38.560±1.647	113.127±4.174	0.465±0.018[b]	0.972±0.089	0.621±0.033

*: p<0.05; NS: Non-significant (p>0.05); X: Least square mean; SE: Standard error.

Table 3. Feed efficiency of calves at different time periods.

		Pre-weaning (kg)	Weaning to 4 months of age (kg)	Birth to 4 months of age(kg)
	N	X±SE	X±SE	X±SE
Overall mean		2.254±0.079	3.010±0.222	2.644±0.102
Breed		NS	*	*
Brown Swiss	26	2.148±0.123	2.551±0.337	2.445±0.155
Holstein-Friesian	41	2.361±0.096	3.469±0.268	2.843±0.124
Sex		NS	NS	NS
Female	27	2.224±0.120	2.798±0.337	2.540±0.155
Male	40	2.285±0.098	3.223±0.268	2.747±0.124
Weaning weight (kg)		NS	NS	NS
60	18	2.387±0.140	3.206±0.383	2.810±0.177
65	19	2.169±0.139	3.145±0.381	2.704±0.176
70	18	2.132±0.143	2.915±0.392	2.601±0.181
75	12	2.330±0.186	2.775±0.534	2.460±0.247

* p<0.05; NS: Non-significant (p>0.05); X: Least square mean; SE: Standard error.

Sex and weaning weight had no significant effect on feed conversion at various time periods.

Least square means and standard errors for body measurements at different time periods are presented in Table 4. Holstein-Friesian was significantly superior to Brown Swiss calves in terms of body length and hearth girth growth in the pre-weaning period (p<0.05). Similar results were also observed in the period from birth to four months of age (p<0.05). Breed had no significant

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effect on other measurements such as height at withers, chest depth and cannon bone girth. Growth of different body measurements was not influenced by sex. No statistical difference was found among weaning weight groups in terms of growth of body measurements in the periods from weaning and birth to four months of age. However, growth of chest depth in the group weaned at 60 kg was lower than the other three weaning weight groups ($p<0.05$).

Least square means and standard errors for behavioral activities of calves at different periods are presented in Table 5. Breed had an effect ($p<0.05$) on standing and lying behavior of calves. Brown Swiss spent more time standing and less time lying compared to Holstein calves in the pre-weaning stage. Similar results were also observed in the period from birth to four months of age. However, in the post-weaning period only the time spent lying was significantly higher in Holstein calves.

Sex effect on behavior was also analyzed. There was no significant difference between sex groups in the pre-weaning period. Male calves spent more time lying between weaning and four months of age ($p<0.05$). Standing behavior was significantly higher in female calves in the period from birth to four months of age ($p<0.05$).

Weaning weight had no effect on behavior in the period from weaning to four months of age. Comparable results were also observed in the 4-month period starting from birth. While there was no difference among groups in terms of standing, lying or feeding, the water drinking behavior was notably ($p<0.05$) higher during the pre-weaning period in calves weaned at 75 kg of BW.

Discussion

Greater weight gain in the early life of calves might influence later performance of dairy heifers (Nikkhah and Alimirzaei, 2022). There was no significant difference between both breeds in terms of daily weight gain in the pre-weaning period and first four months. However, Brown Swiss calves had notably higher weight gain in the period between weaning and four months of age ($p<0.05$). These findings agree with Güler *et al.* (2003), who reported higher daily weight gain for Brown Swiss calves compared to Holstein-Friesian. Sex had no effect on daily weight gain of calves in any stage of the first four months of life. Comparable results were also reported by Lambertz *et al.* (2015).

Early weaning may result in deficiencies in weight gain and growth performance. Daily weight gain of calves weaned at 60 kg was significantly inferior compared to the other three groups in the pre-weaning period ($p<0.05$). This result is supported by Miller-Cushon *et al.* (2013), Yavuz *et al.* (2015), Abbas *et al.* (2017), and Khattak *et al.* (2018) who reported that late weaning increases BW. In contrast, there was no difference among weaning weight groups in terms of four-month weight and daily weight gains in the periods between weaning to four months of age as well as birth to four months of age. Our findings show that the gap between light and heavy weaned calves in terms of daily weight gain and BW is close in the post-weaning period. Our results agree with the findings reported by Hopkins (1997) and Koçak and Güneş (2005).

Genotype is a major factor affecting calf efficiency. Brown Swiss were superior to Holstein calves in terms of feed efficiency in the post-weaning and 4-month periods ($p<0.05$). Our results agree with Güler *et al.* (2003). Sex had no significant effect on feed efficiency. These results are comparable to the findings by Koçyiğit *et al.* (2015). Although feed conversion efficiency of calves increased gradually as weaned weight increased, this difference among groups was not significant. Similarly, Winter *et al.* (1985) and Kehoe *et al.* (2007) reported that weaning at different ages had no effect on feed efficiency of calves.

Adequate body development in early life is essential for calves to achieve acceptable body structure later in life. Breed is a source of variation for changes in different body measurements.

Table 4. Intraoperative fibrinolytic treatment allocation and monitoring on days 1, 7, 30, 60, and 90 post-surgery.

		Pre-weaning (cm)					Weaning to 4 months of age (cm)					Birth to 4 months of age (cm)				
		Body length	**Height at withers**	**Chest depth**	**Hearth girth**	**Cannon bone girth**	**Body length**	**Height at withers**	**Chest depth**	**Hearth girth**	**Cannon bone girth**	**Body length**	**Height at withers**	**Chest depth**	**Hearth girth**	**Cannon bone girth**
	N	X±SE	X±SE	X±SE	X±SE	X±SE	X±SE	X±SE	X±SE	X±SE	X±SE	X±SE	X±SE	X±SE	X±SE	X±SE
Overall mean		14.1±0.8	9.8±0.5	6.3±0.3	16.6±0.6	0.9±0.1	12±0.6	9±0.5	6.1±0.3	15.6±0.6	0.9±0.1	26.1±0.8	18.8±0.5	12.5±0.3	32.2±0.6	1.8±0.1
Breed		*	NS	NS	*	NS	*	NS	NS	*	NS	NS	NS	NS	NS	NS
Brown Swiss	26	12.7±1.2	9±0.8	6.4±0.5	15.4±1	0.9±0.1	13.3±0.9	9.4±0.8	6.5±0.5	17.1±1.0	1.1±0.1	26.0±1.3	18.4±0.8	12.9±0.5	32.4±0.9	1.9±0.1
Holstein-Friesian	41	15.6±0.9	10.6±0.6	6.3±0.4	17.8±0.8	0.8±0.1	10.7±0.7	8.6±0.6	5.7±0.4	14.1±0.8	0.9±0.1	26.3±1.0	19.1±0.6	12.0±0.4	31.9±0.7	1.7±0.1
Sex		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Female	27	14.8±1.2	10.4±0.7	6.7±0.4	17.5±0.9	1.0±0.1	11.5±0.9	8.7±0.8	5.9±0.4	15.4±1	0.8±0.1	26.3±1.3	19.1±0.8	12.6±0.5	32.8±0.9	1.8±0.1
Male	40	13.4±1	9.2±0.6	6±0.4	15.7±0.8	0.8±0.1	12.6±0.7	9.2±0.7	6.4±0.4	15.8±0.8	1.1±0.1	26±1.1	18.5±0.7	12.3±0.4	31.5±0.7	1.8±0.1
Weaning weight (kg)			NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
60	18	11.6±1.4	8.6±0.9	5.4±0.5a	14.4±1.1	0.7±0.2	13.9±1.1	10.1±1	6.7±0.5	17.3±1.2	1.3±0.2	25.5±1.6	18.7±1	12.1±0.6	31.7±1.1	1.9±0.2
65	19	13.1±1.4	9±0.9	6±0.5a	16.2±1.1	0.9±0.2	12.4±1	9.9±0.9	6.3±0.5	16.3±1.1	0.8±0.2	25.5±1.5	18.8±1	12.4±0.6	32.5±1.1	1.7±0.2
70	18	16.2±1.4	9.8±0.9	6±0.5a	17.1±1.1	0.8±0.2	11.8±1.1	8.5±1.0	6.4±0.5	15.2±1.2	1.0±0.2	28±1.5	18.4±1	12.5±0.6	32.3±1.1	1.8±0.2
75	12	15.6±1.7	11.8±1.1	7.9±0.7b	18.8±1.4	1.1±0.2	9.9±1.3	7.4±1.2	5±0.7	13.4±1.4	0.7±0.2	25.5±1.9	19.2±1.2	12.9±0.7	32.2±1.4	1.8±0.2

*: $p<0.05$; NS: Non-significant ($p>0.05$); X: Least square mean; SE: Standard error.

Table 5. Behavioral activity of calves at different time periods.

		Behavior of calves before weaning (%)				Behavior between weaning and 4 months of age (%)				Behavior between birth and 4 months of age (%)						
		Standing	Lying	Feeding	Drinking water	Standing	Lying	Feeding	Drinking water	Standing	Lying	Feeding	Drinking water	Chest depth	Hearth girth	Cannon bone girth
	N	X±SE	X±SE	X±SE	X±SE	X±SE	X±SE	X±SE	X±SE	X±SE	X±SE	X±SE	X±SE	X±SE	X±SE	X±SE
Overall mean		54.1±1.2	38.8±1.2	6.8±0.4	0.3±0.1	46.5±1.4	24.8±1.3	27.8±1.5	0.9±0.2	50.5±1	33.8±1	15.1±0.6	0.5±0.1	12.5±0.3	32.2±0.6	1.8±0.1
Breed		*	*	NS	NS	NS	*	NS	NS	*	*	NS	NS	NS	NS	NS
Brown Swiss	26	57.3±1.9	36.3±1.9	6.1±0.6	0.3±0.1	48.1±2.3	21.5±2.1	29.5±2.5	0.9±0.3	52.7±1.6	31.1±1.6	15.6±1.0	0.6±0.1	12.9±0.5	32.4±0.9	1.9±0.1
Holstein-Friesian	41	50.8±1.3	41.4±1.3	7.5±0.5	0.3±0.1	44.9±1.6	28.1±1.5	26.2±1.7	0.8±0.2	48.3±1.1	36.6±1.1	14.7±0.7	0.4±0.1	12.0±0.4	31.9±0.7	1.7±0.1
Sex		NS	NS	NS	NS	NS	*	NS	NS	*	NS	NS	NS	NS	NS	NS
Female	27	55.3±1.8	37.5±1.8	6.7±0.6	0.4±0.1	50.1±2.2	21.6±2.0	27.6±2.4	0.7±0.3	52.5±1.5	32.1±1.5	14.9±1.0	0.5±0.1	12.6±0.5	32.8±0.9	1.8±0.1
Male	40	52.8±1.4	40.2±1.4	6.9±0.5	0.2±0.1	42.9±1.7	28.0±1.6	28.1±1.8	1.0±0.2	48.5±1.2	35.6±1.2	15.4±0.8	0.5±0.1	12.3±0.4	31.5±0.7	1.8±0.1
Weaning weight (kg)		NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
60	18	57.2±2.2	36.5±2.1	6.1±0.7	0.2±0.1[a]	44.7±2.6	25.9±2.4	29.0±2.8	0.4±0.3	51.5±1.8	31.6±1.8	16.6±1.2	0.3±0.1	12.1±0.6	31.7±1.1	1.9±0.2
65	19	53.4±2.1	40.2±2.1	6.2±0.7	0.2±0.1[a]	47.5±2.6	24.2±2.4	27.3±2.8	1.0±0.3	50.8±1.8	33.4±1.8	15.3±1.1	0.5±0.1	12.4±0.6	32.5±1.1	1.7±0.2
70	18	55.0±2.0	37.7±2.0	7.2±0.7	0.2±0.1[a]	46.6±2.4	24.1±2.2	28.4±2.6	0.8±0.3	51.6±1.7	33.2±1.6	14.7±1.1	0.4±0.1	12.5±0.6	32.3±1.1	1.8±0.2
75	12	50.7±2.6	41.1±2.5	7.7±0.9	0.5±0.1[b]	47.2±3.1	25.0±2.9	26.6±3.4	1.2±0.4	48.1±2.2	37.0±2.1	14.1±1.4	0.8±0.2	12.9±0.7	32.2±1.4	1.8±0.2

*: $p<0.05$; NS: Non-significant ($p>0.05$); X: Least square mean; SE: Standard error.

Increases in body length and hearth girth of Holstein-Friesian were higher than Brown Swiss calves in the pre-weaning period. However, in the post-weaning period until four months of age, Brown Swiss calves were superior to Holsteins in terms of body length and hearth girth ($p<0.05$). The differences for these measurements were not significant in the period between birth and four months of age. Ertugrul *et al.* (2000) reported that Holstein calves had higher average values for body measurements than Brown Swiss from birth to 6 months of age. Their findings differ with our results. Weaning weight did not have significant effect on body measurements, except for chest depth, which was higher in the pre-weaning period for the group weaned at 75 kg. Similar results have been reported in several studies (Kehoe *et al.*, 2007; Rashid *et al.*, 2013).

Behavioral activities are used as indicators of animal comfort (Anderson, 2001). Lying bout of Holstein-Friesian was significantly longer than Brown Swiss calves in the pre-weaning and 4-month period ($p<0.05$). In contrast, Brown Swiss calves spent more time standing in both post and pre-weaning periods ($p<0.05$). Lying bout of male calves was longer in the post-weaning period ($p<0.05$). On the other hand, female calves spent more time standing compared to male calves between birth and 4-months of age ($p<0.05$). There was no difference between sex groups in other activities and periods. Comparable results were also reported by Koçyiğit *et al.* (2015). Weaning may cause severe stress for calves, especially when the rumen is not developed enough. Changes in the behavior may be used to determine stress and discomfort. In the present study there was no difference among weaning weight groups in terms of behavioral activities, except for water drinking. Our results showed that weaning at lighter weights did not significantly affect the behavioral patterns of dairy calves. The findings by Koçyiğit *et al.* (2015) agree with the results of the present study.

Different weaning weights had a remarkable effect on the cost of calf feeding. Average feeding cost for calves weaned at 60, 65, 70, and 75 kg were USD$2.72, USD$2.77, USD$2.84, and USD$2.96 per kg live weight gain, respectively. Increasing weaning weight resulted in higher feeding costs due to higher amount of milk consumed. Calves weaned at 75 kg consumed approximately 73 L more milk compared to calves weaned at 60 kg. Our results agree with the findings by Bjonklund *et al.* (2013) who reported that feeding cost of calves weaned at 30 days of age (62 kg; USD $3.02) was lower than that of calves weaned at 90 days (108 kg) in an organic production system. Similarly, Koçyiğit *et al.* (2015) reported that feeding cost of calves weaned at lighter (53.7 kg) and heavier (74.3 kg) weights were USD$2.18 and USD$2.41, respectively. Comparable results were also found by Khattak *et al.* (2018) who reported lower feeding costs for calves weaned at 70 days compared to those weaned at 90 and 110 days of age.

In conclusion, our findings provide clear evidence that weaning dairy calves at 60, 65, 70, and 75 kg of BW does not have a significant effect on growth performance, weight gain or feed efficiency during a 4-month period. Moreover, no sign of stress was observed in the early weaned calves as compared to calves weaned at heavier weights. However, higher weaning weights resulted in higher feeding cost. This study suggest that dairy calves can be weaned at 60 kg of BW without any detrimental effect on performance and the feeding cost per kg weight gain is significantly lower when compared to higher weaning weights.

Declarations

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Conflicts of interest

The authors declare they have no conflicts of interest regarding the work presented in this report.

Author contributions

RK, MY, RA, and AD designed and supervised the study. RK, VFÖ, OG, AD, and MAA collected the data. RA made the statistical analysis. The manuscript was written by MY and VFÖ. All authors contributed to the critical revision of the manuscript. The final version of the manuscript was approved by all authors.

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